Synchronization: Implementing Barriers Promises + Futures

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CS378H

Today

- Questions?
- Administrivia
  - Lab 2 due sooner than you'd like
- Material for the day
  - Barrier implementation
  - Promises & Futures

- Acknowledgements
  - Thanks to Gadi Taubenfield: I borrowed from some of his slides on barriers

Faux Quiz (answer any N, 5 min)

- How are promises and futures related? Since there is disagreement on the nomenclature, don't worry about which is which—just describe what the different objects are and how they function.

Barriers

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Review: Barrier Basics

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- *Coordination mechanism*
- *participants wait until all reach same point.*
- *Once all reach it, all can pass.*

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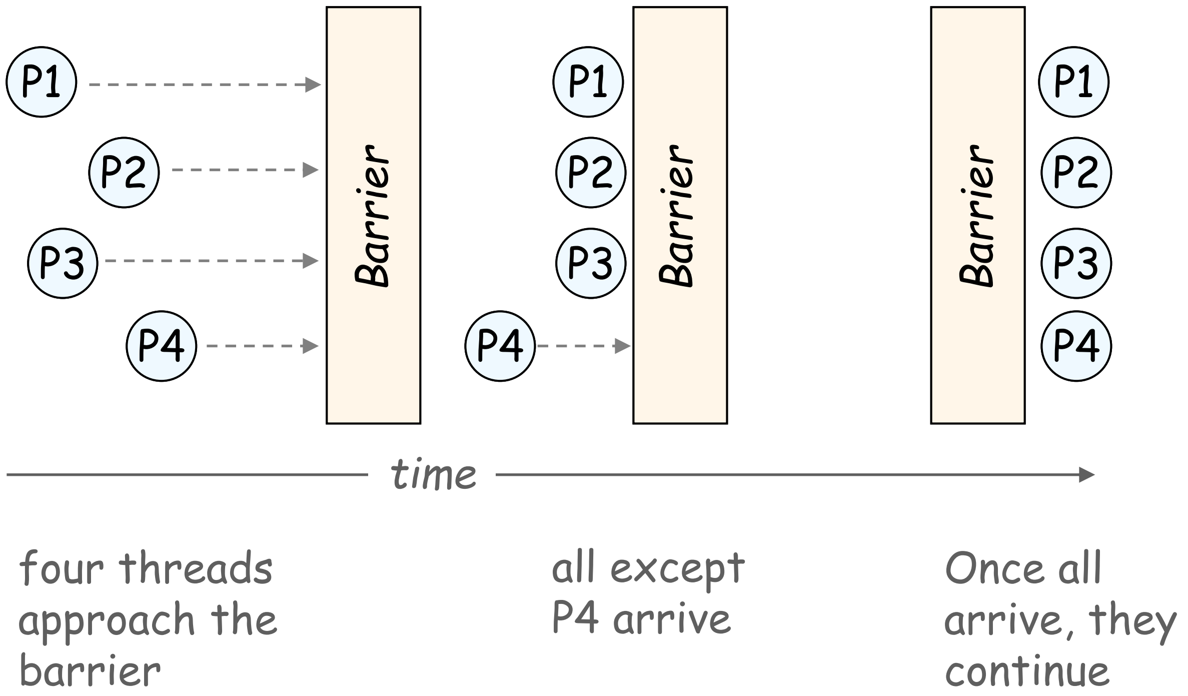

Review: Barrier Basics

- *Coordination mechanism*
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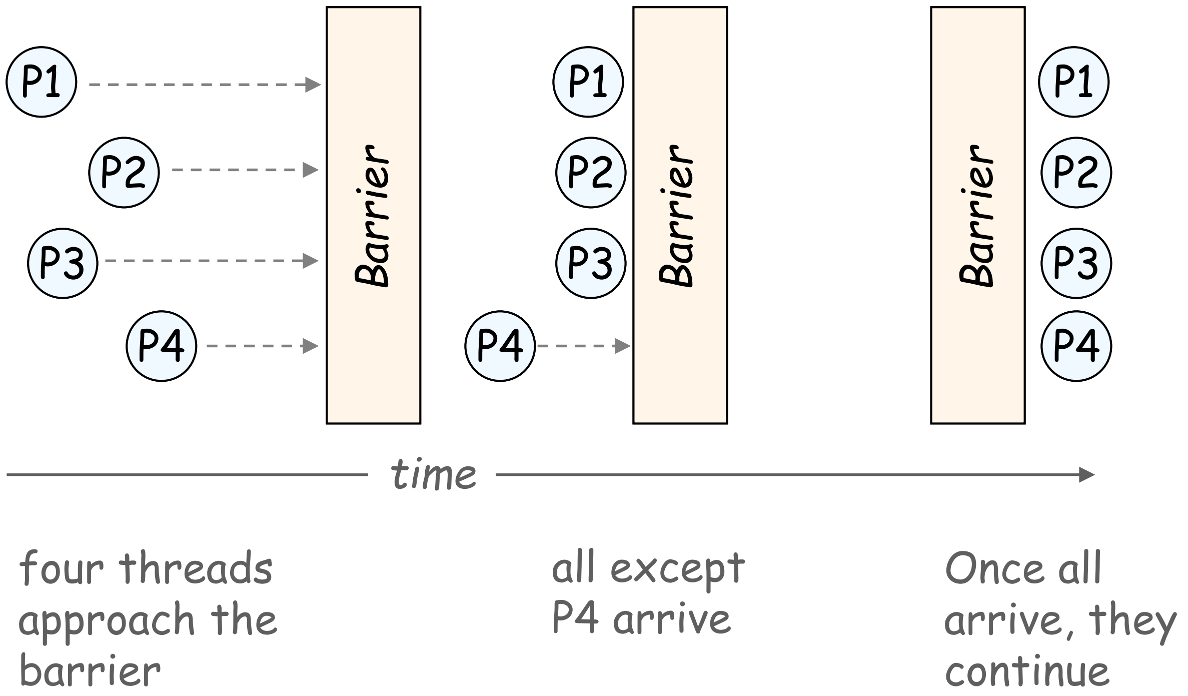
- *Once all reach it, all can pass.*
- ***Workhorse of BSP programming models***



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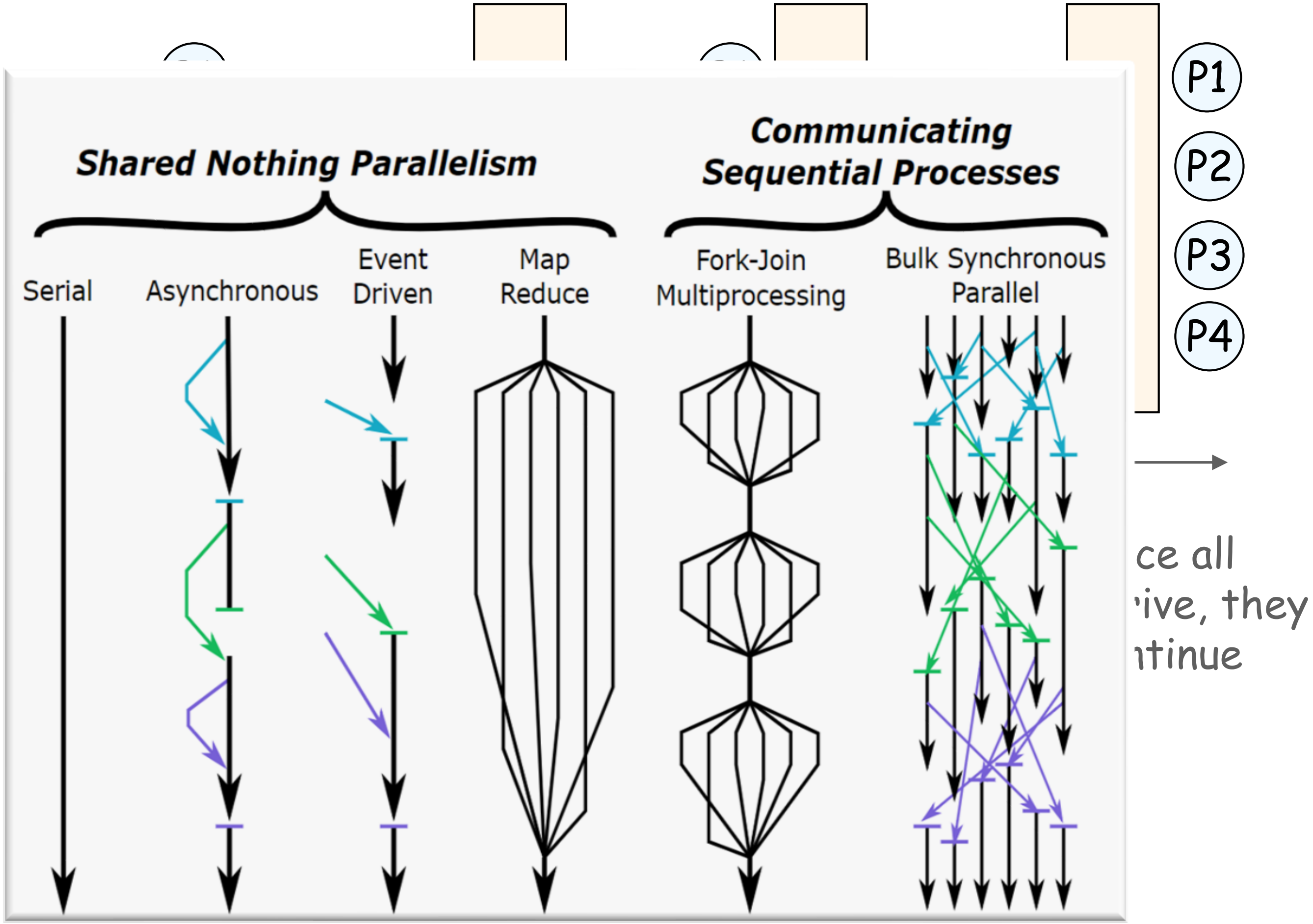

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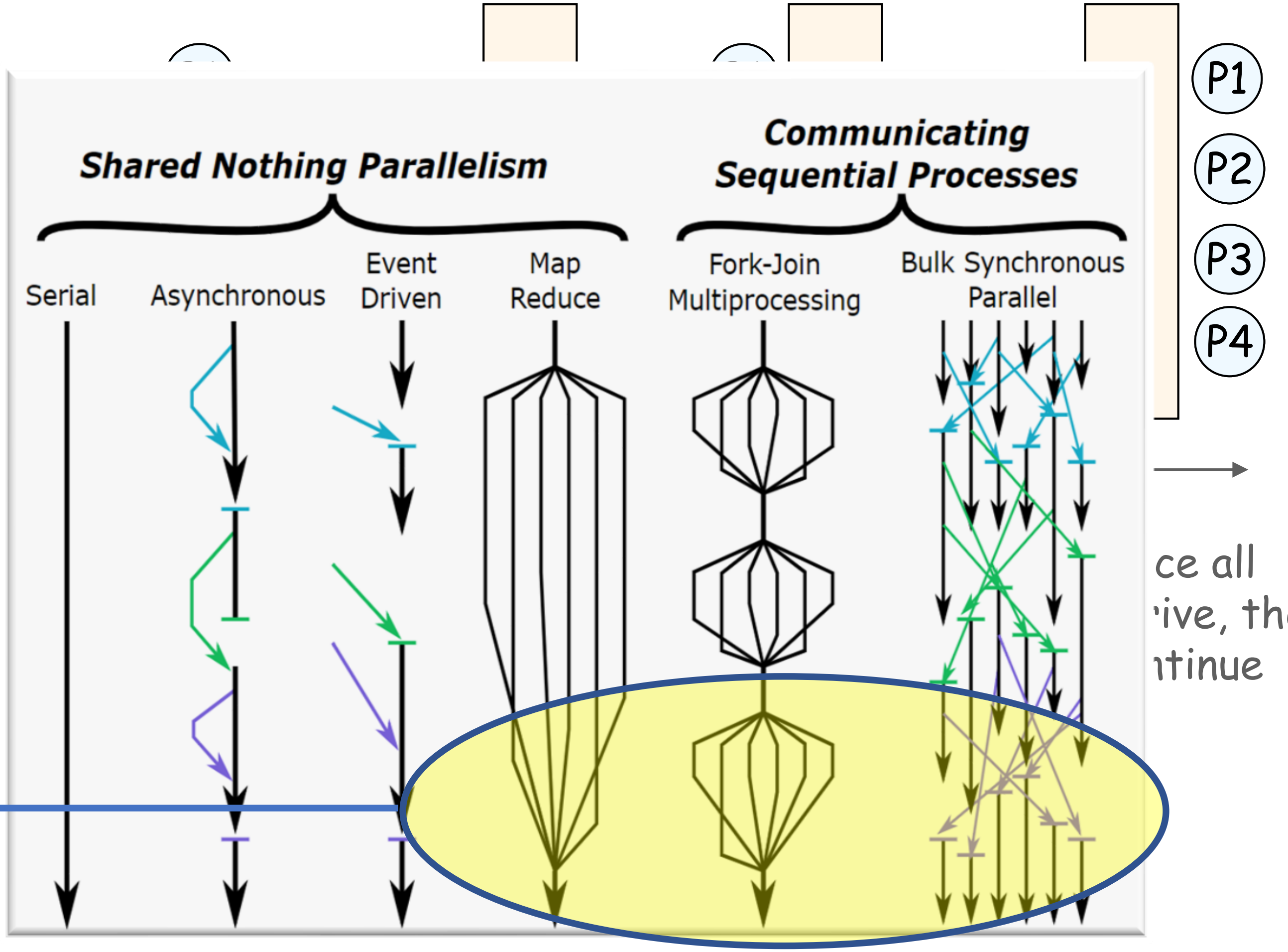

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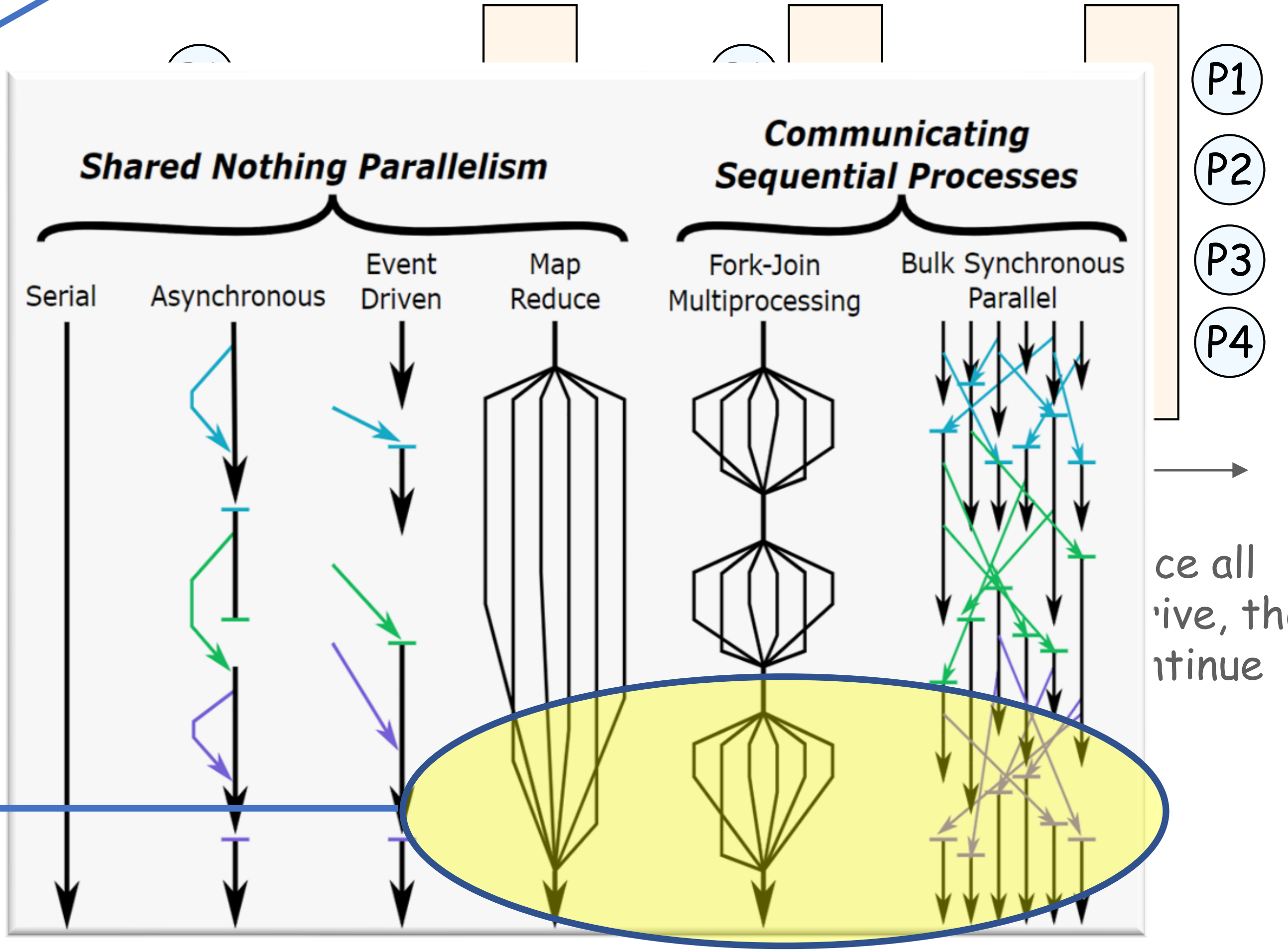
Fundamental primitive in many parallel models

Review: Barrier Basics

Can you make a lock with a barrier?

- Coordination mechanism
- *participants wait until all reach same poin*
- *Once all reach it, all can pass.*
- ***Workhorse of BSP programming models***



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Fundamental primitive in many parallel models

Barriers based on counters

Counter Barrier Ingredients

Fetch-and-Increment register

- A shared register that supports a F&I operation:
- Input: register *r*
- Atomic operation:
  - *r* is incremented by 1
  - the old value of r is returned

```
function fetch-and-increment (r : register)
        orig_r := r;
        r:= r + 1;
        return (orig_r);
end-function
```

Await

- For brevity, we use the **await** macro
- Not an operation of an object
- This is just "spinning"

```
macro await (condition : boolean condition)
        repeat
                cond = eval(condition);
        until (cond)
end-macro
```

Simple Barrier Using an Atomic Counter

shared	counter: fetch and increment reg. – {0,..n}, initially = 0
	go: atomic bit, initial value does not matter
local	local.go: a bit, initial value does not matter
	local.counter: register

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local.go := go
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if local.counter + 1 = n then
        counter := 0
        go := 1 - go
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Pros/Cons?

Simple Barrier Using an Atomic Counter

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```
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2   local.counter := fetch-and-increment (counter)
3   if local.counter + 1 = n then
4           counter := 0
5           go := 1 - go
6   else await(local.go ≠ go)
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Pros/Cons?

Simple Barrier Using an Atomic Counter

shared counter: fetch and increment reg. – {0,..n}, initially = 0
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Pros/Cons?

- There is high memory contention on *go* bit

Simple Barrier Using an Atomic Counter

shared counter: fetch and increment reg. – {0,..n}, initially = 0
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local.go := go
local.counter := fetch-and-increment (counter)
if local.counter + 1 = n **then**
    counter := 0
    go := 1 - go
else await(local.go ≠ go)

Pros/Cons?

- There is high memory contention on *go* bit
- Reducing the contention:
  - Replace the *go* bit with *n* bits: *go*[1],…,*go*[*n*]
  - Process p_i may spin only on the bit *go*[*i*]

A Local Spinning Counter Barrier

Program of a Thread i

shared	counter: fetch and increment reg. – {0,..n}, initially = 0
	go[1..n]: array of atomic bits, initial values are immaterial
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A Local Spinning Counter Barrier

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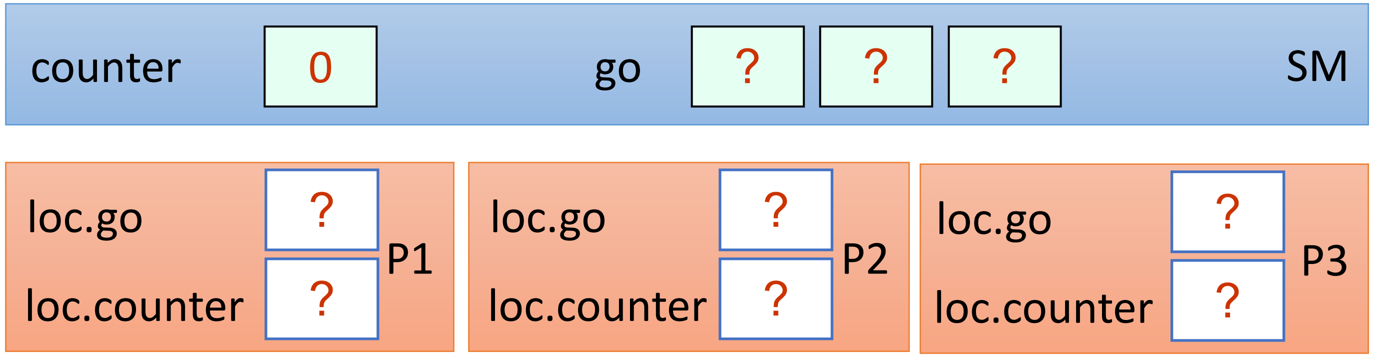
A Local Spinning Counter Barrier

Example Run for n=3 Threads

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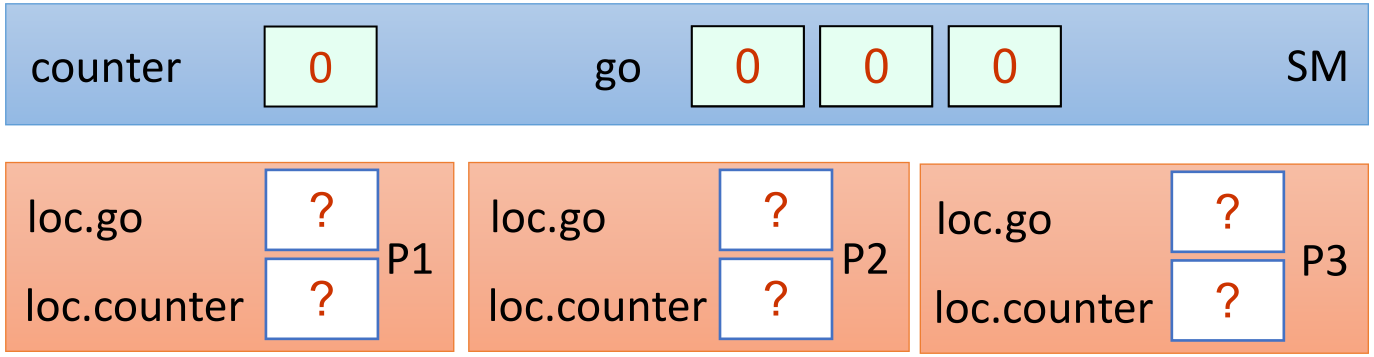


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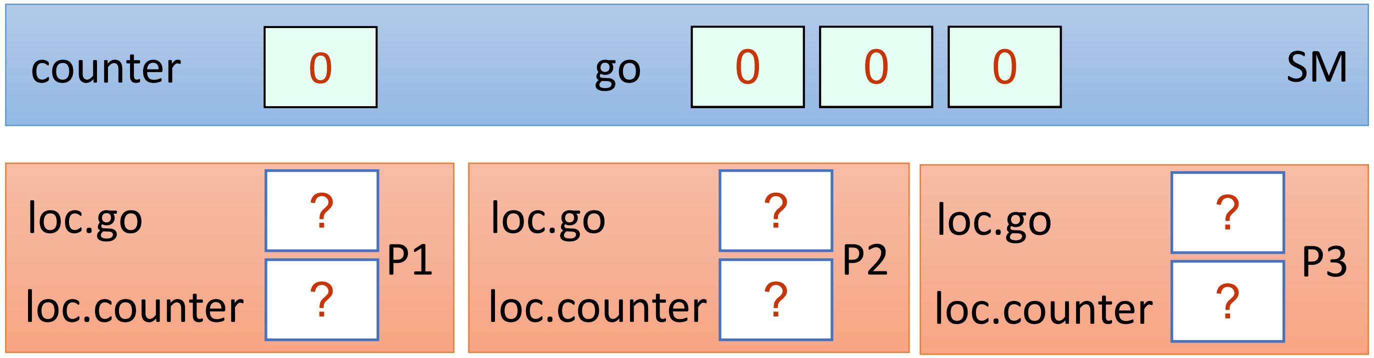

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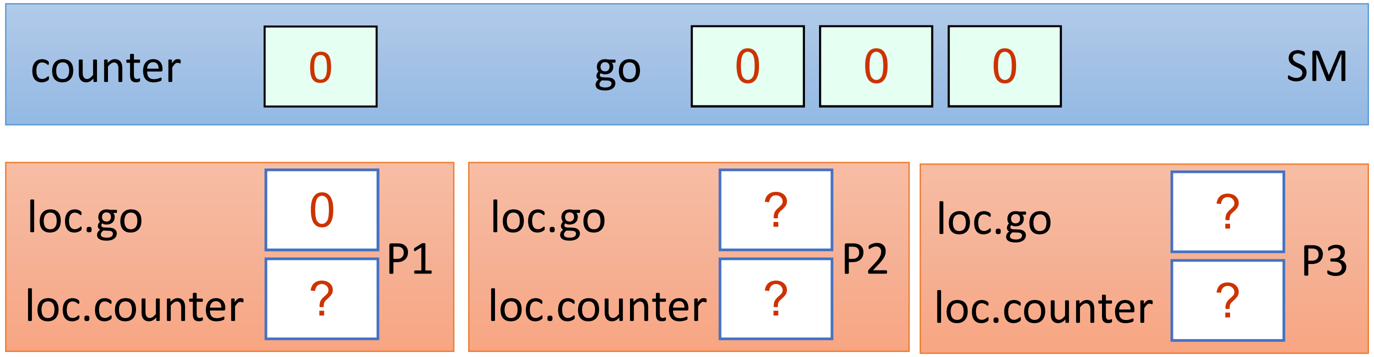


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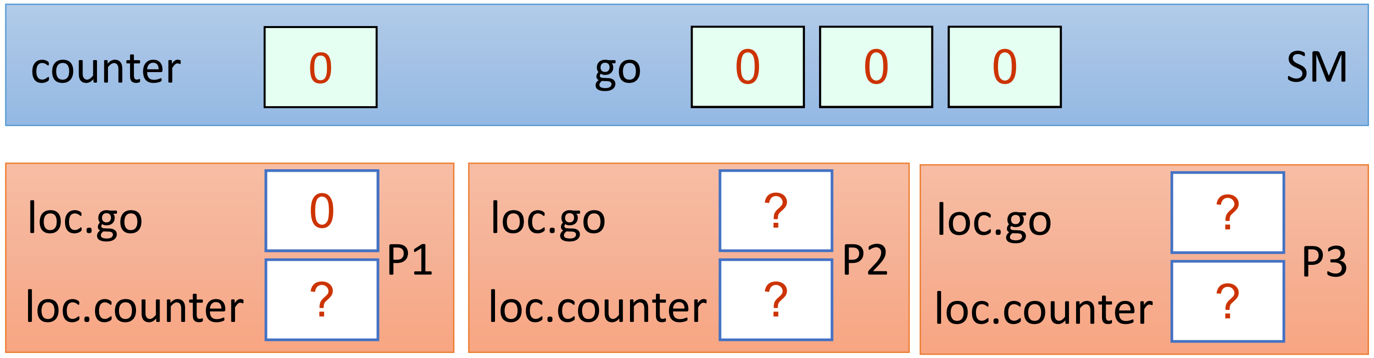

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A Local Spinning Counter Barrier

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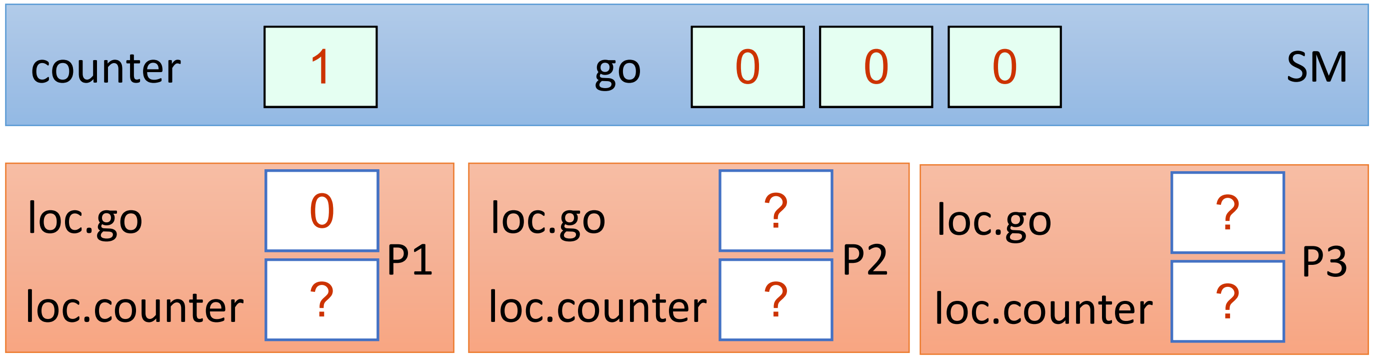

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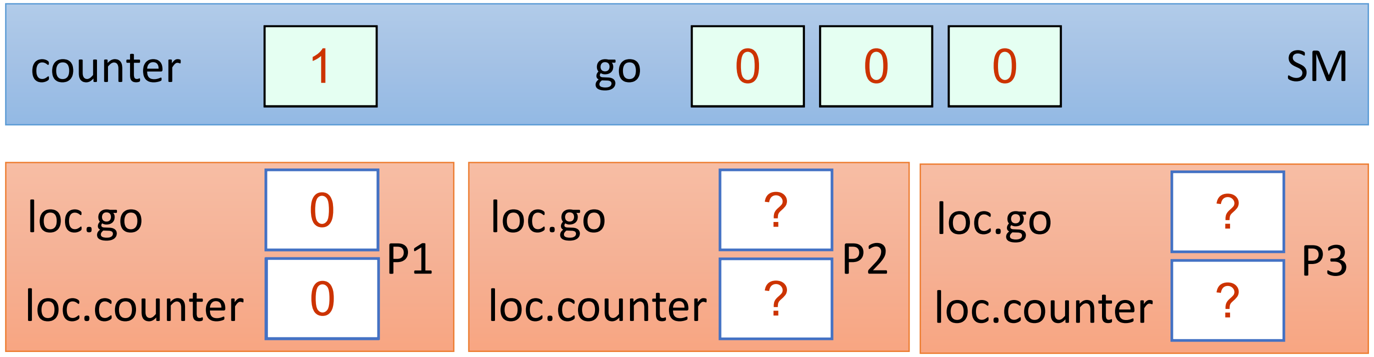

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A Local Spinning Counter Barrier

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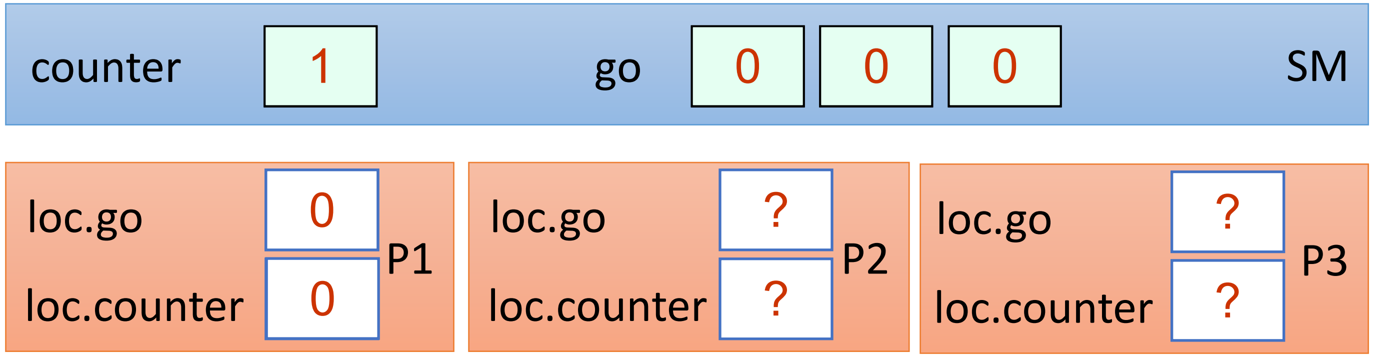

P1 → (line 3)

```
local.go := go[i]
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if local.counter + 1 = n then
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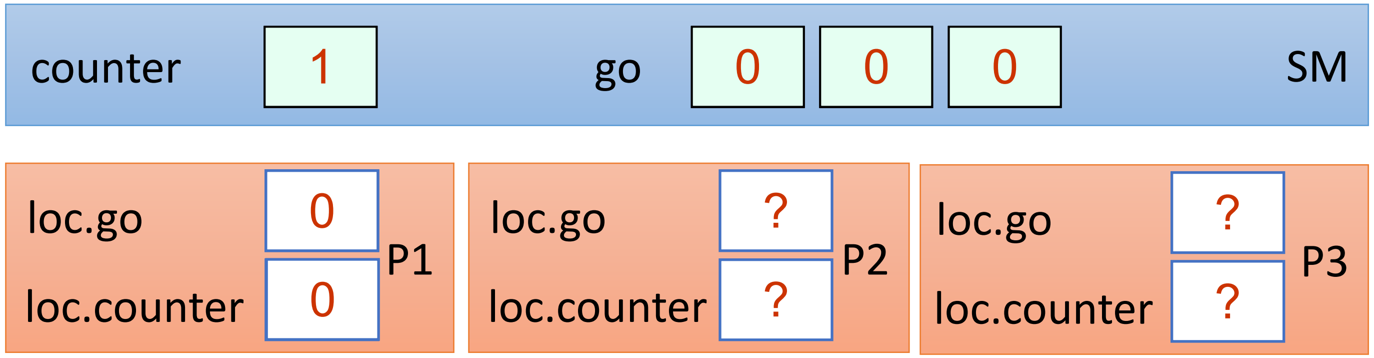
```

A Local Spinning Counter Barrier

Example Run for n=3 Threads

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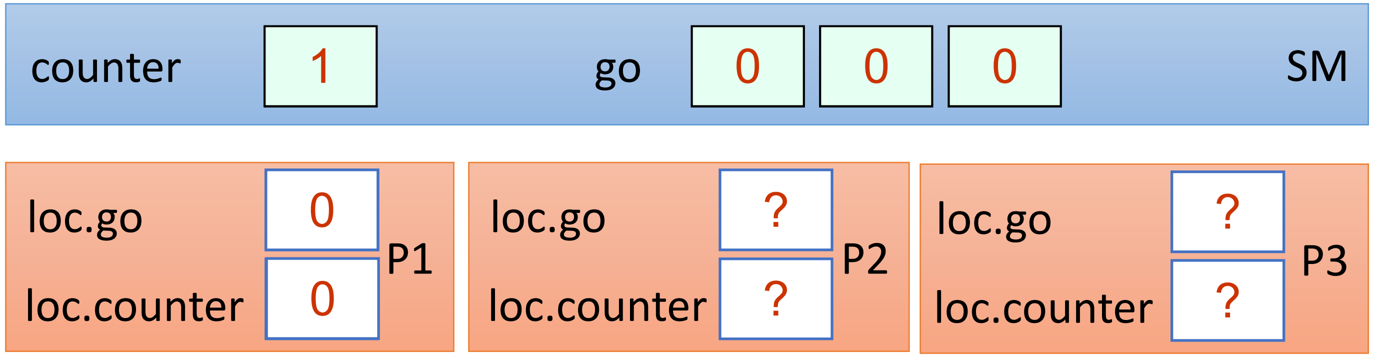
P1 →

0+1≠3

A Local Spinning Counter Barrier

Example Run for n=3 Threads

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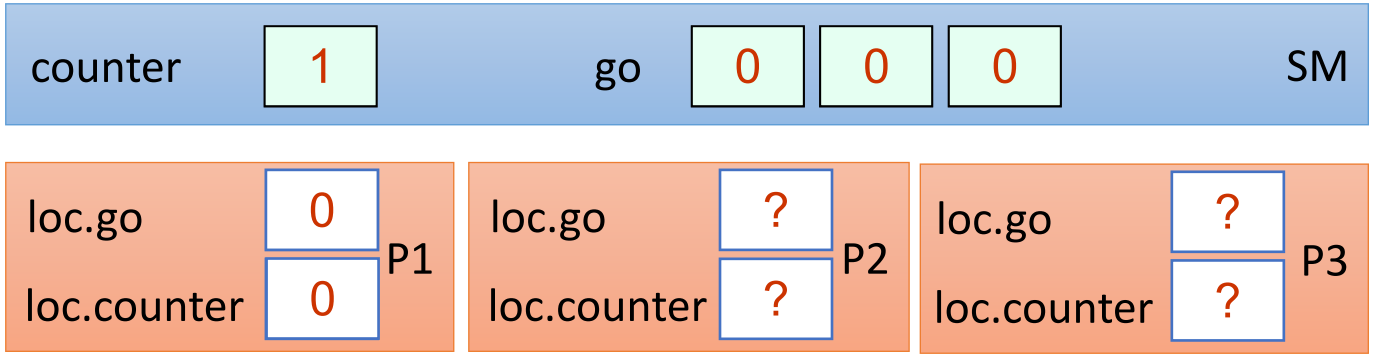


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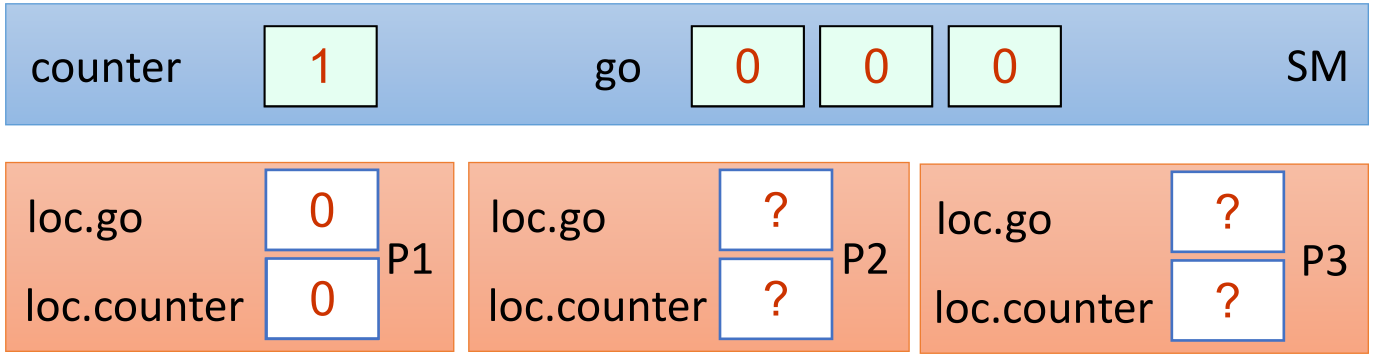
```

P1 → (line 6)

P1 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads



P2 →

```
local.go := go[i]
local.counter := fetch-and-increment (counter)
if local.counter + 1 = n then
        counter := 0
        for j=1 to n { go[j] := 1 – go[j] }
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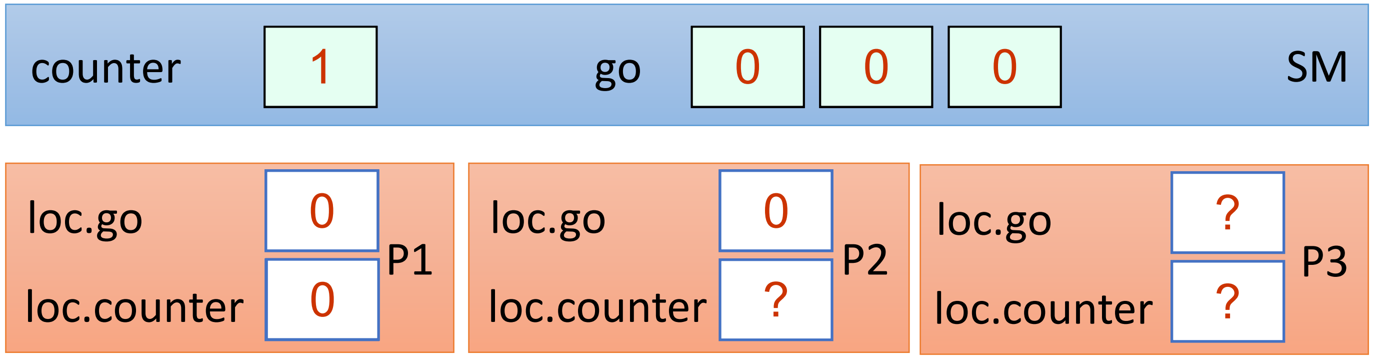
```

P1 →

P1 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads

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```

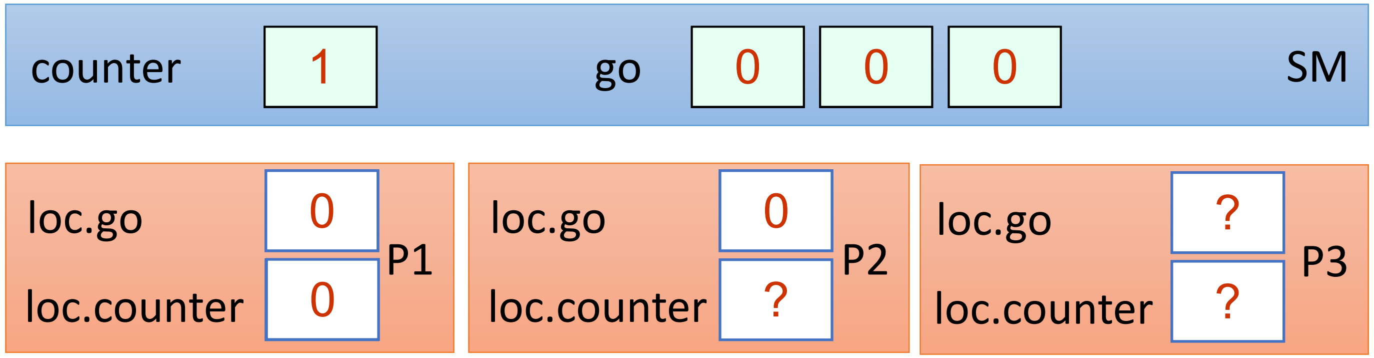
P2 → (line 1)

P1 → (line 6)

P1 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads




```
local.go := go[i]
local.counter := fetch-and-increment (counter)      ← P2
if local.counter + 1 = n then
        counter := 0
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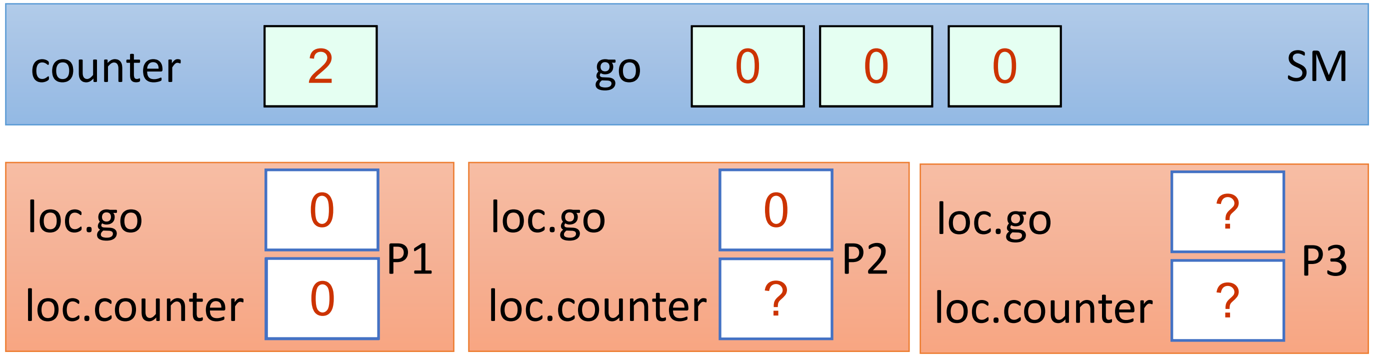
else await(local.go ≠ go[i])                         ← P1
```

P1 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads

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P1 Busy wait

A Local Spinning Counter Barrier

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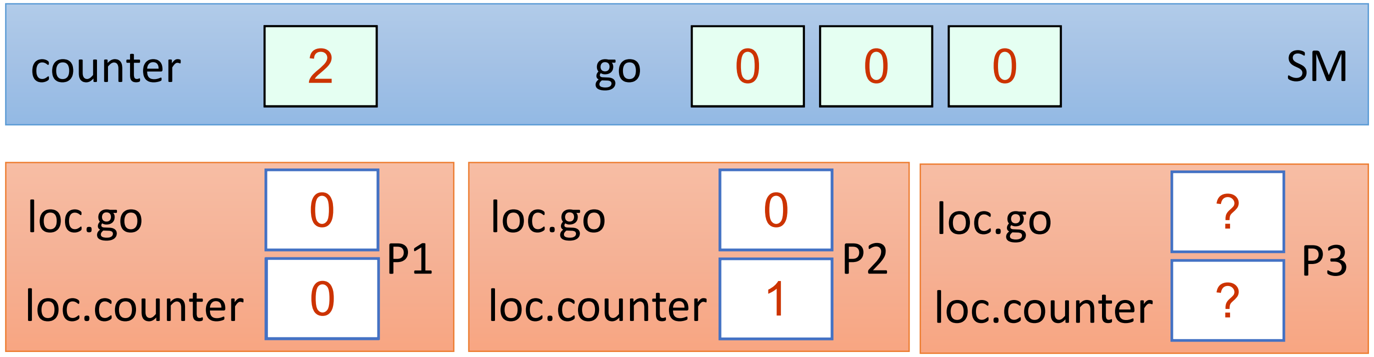


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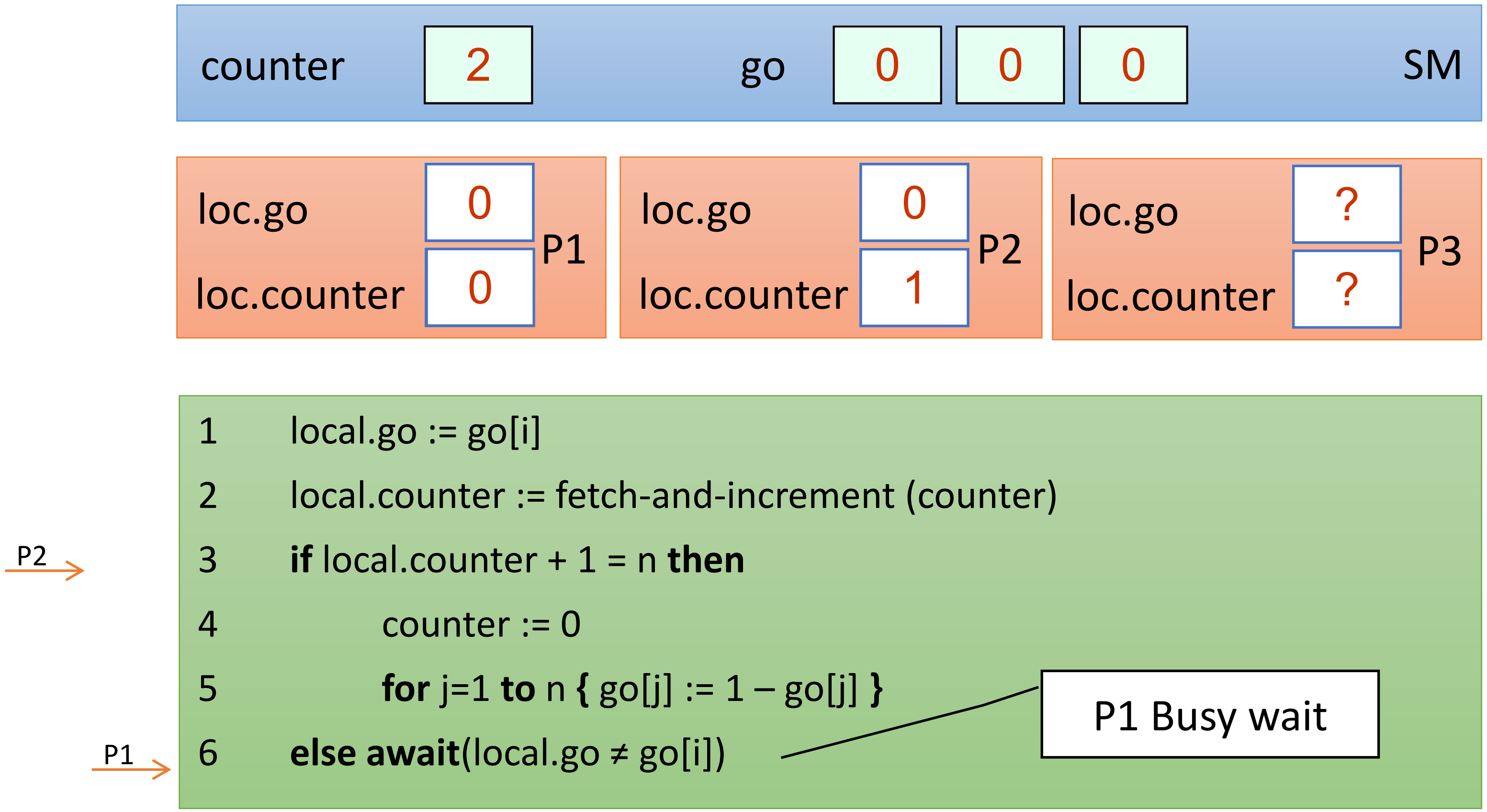
P1 Busy wait

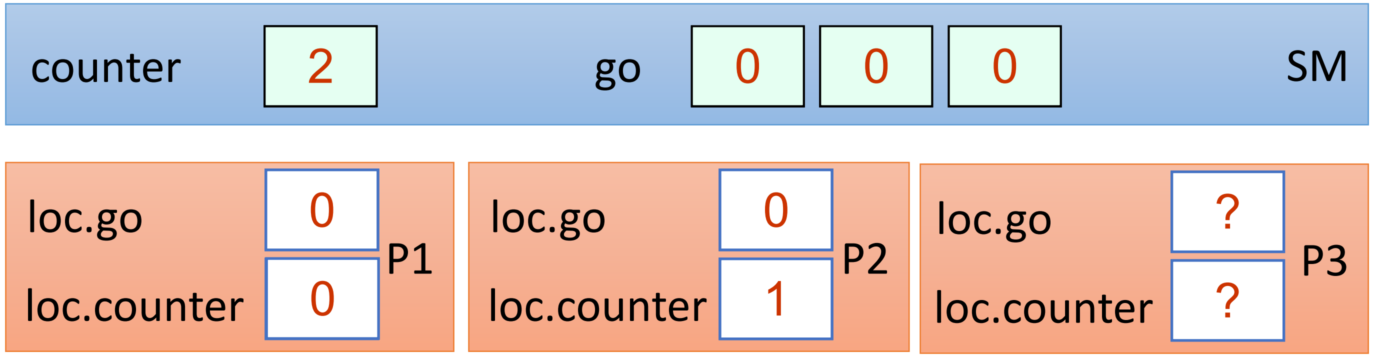
A Local Spinning Counter Barrier

Example Run for n=3 Threads



A Local Spinning Counter Barrier

Example Run for n=3 Threads

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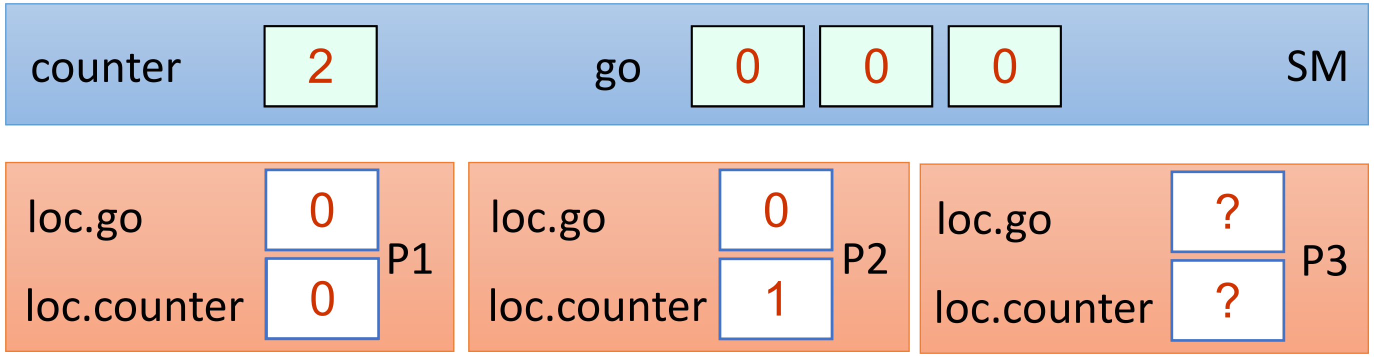
P2 → line 3: 1+1≠3

P1 → line 6: P1 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads

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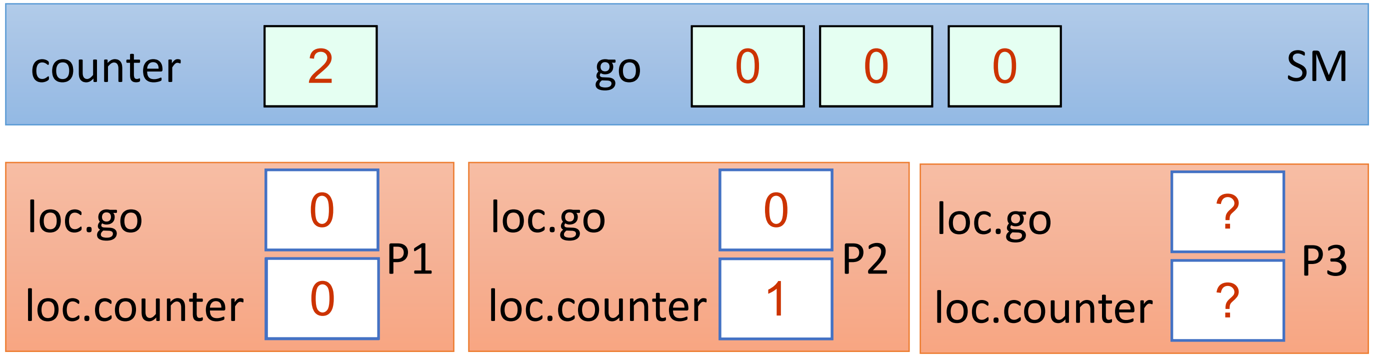
P2 → P1 → (at line 6)

P1,P2 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads

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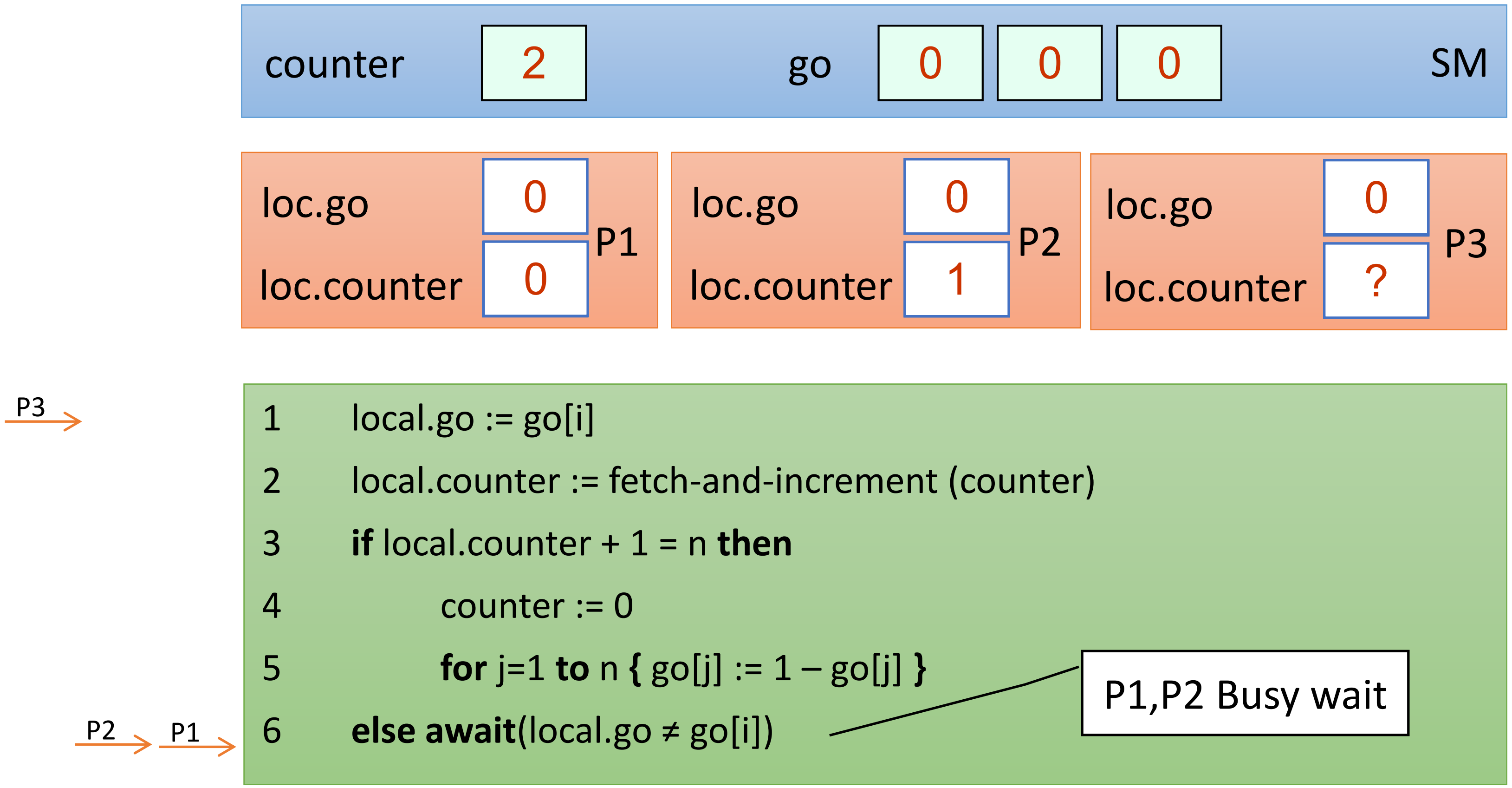
P3 → (at line 1)

P2 → P1 → (at line 6)

P1,P2 Busy wait

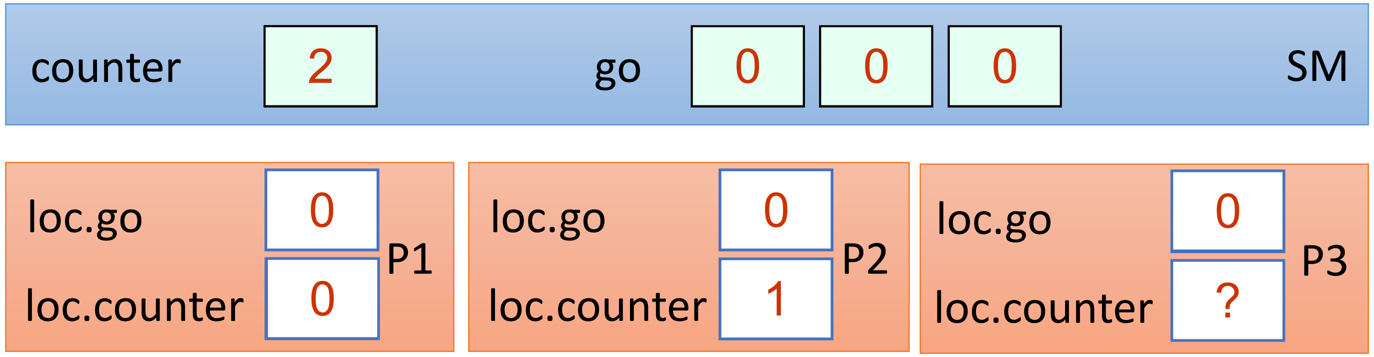
A Local Spinning Counter Barrier

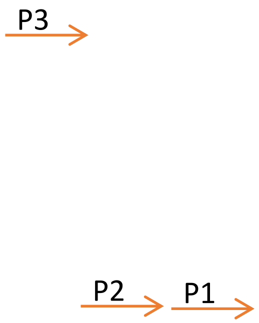
Example Run for n=3 Threads



A Local Spinning Counter Barrier

Example Run for n=3 Threads



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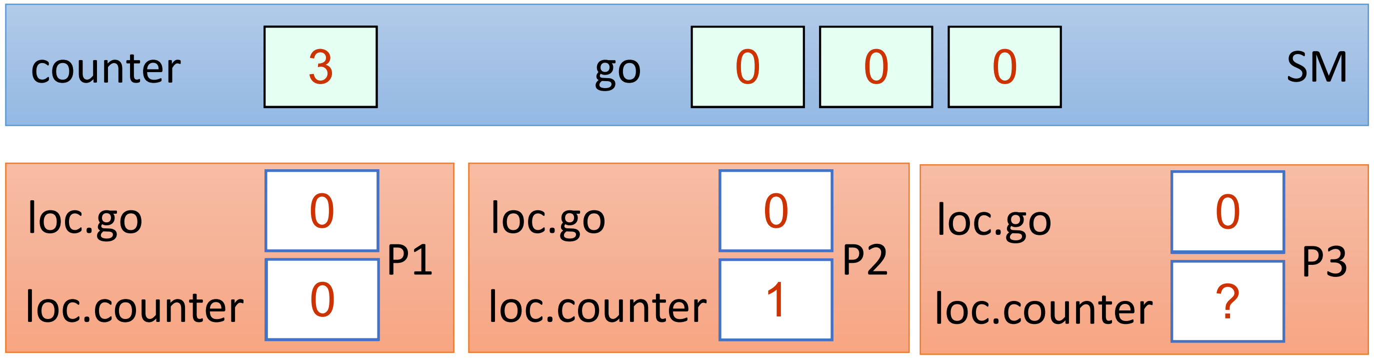
P1,P2 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads



P3

P2 P1

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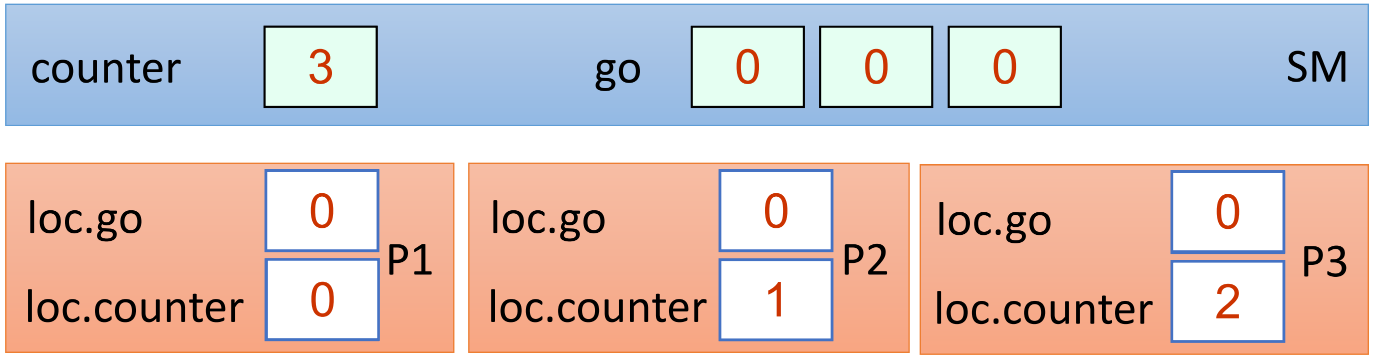
P1,P2 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads

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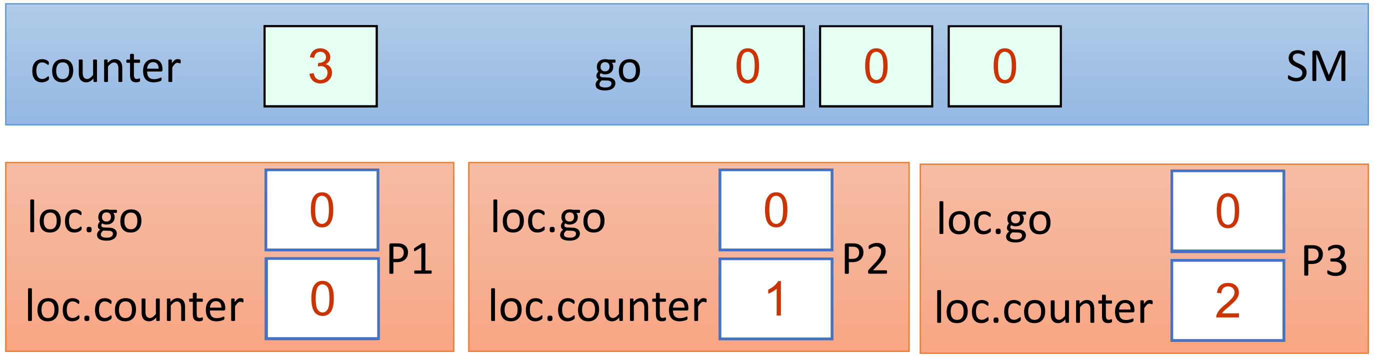
```

P3 → (line 2); P2 → P1 → (line 6)

P1,P2 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads

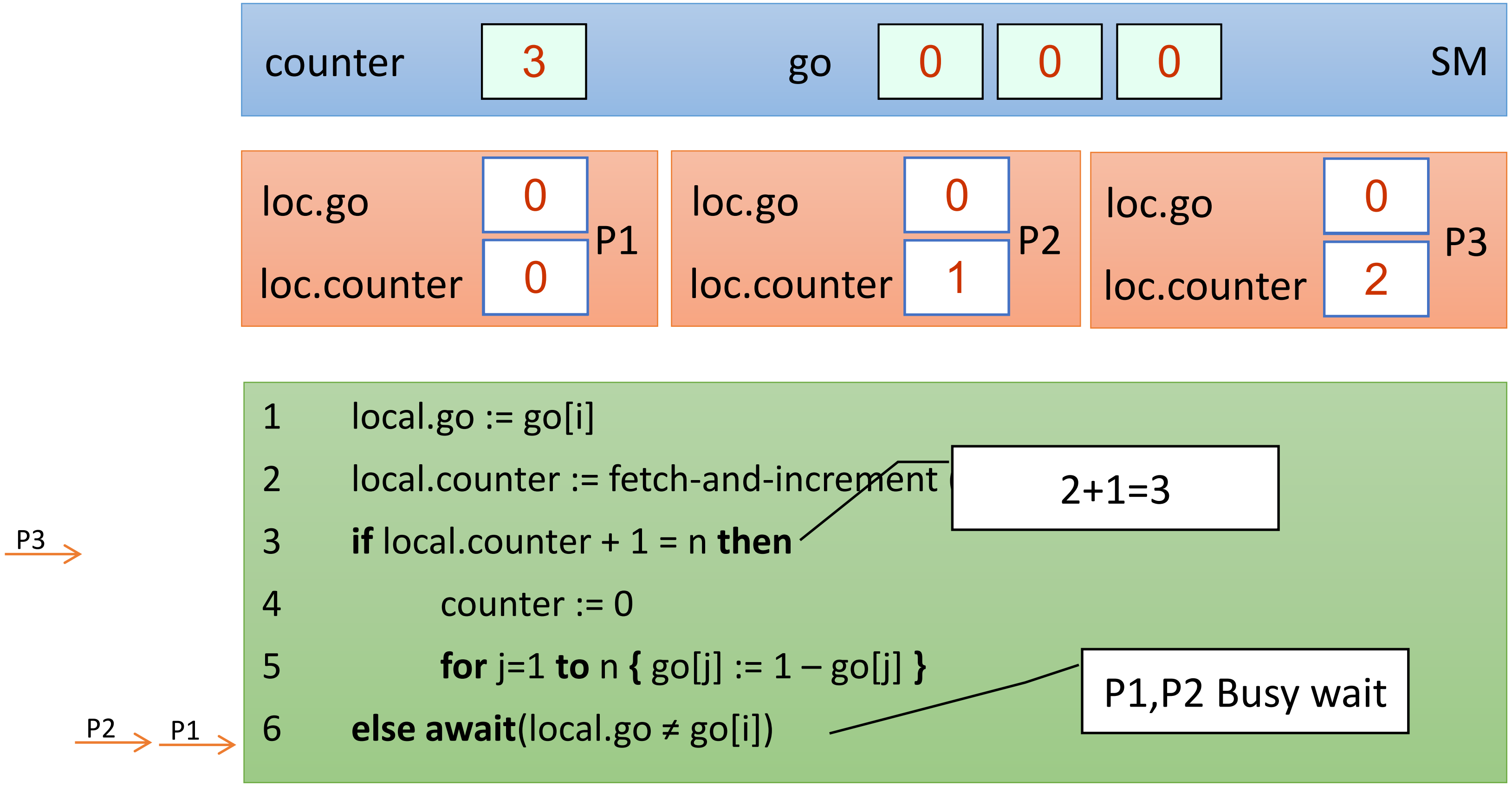



```
local.go := go[i]
local.counter := fetch-and-increment (counter)
if local.counter + 1 = n then          <- P3
    counter := 0
    for j=1 to n { go[j] := 1 – go[j] }
else await(local.go ≠ go[i])           <- P2, P1
```

P1,P2 Busy wait

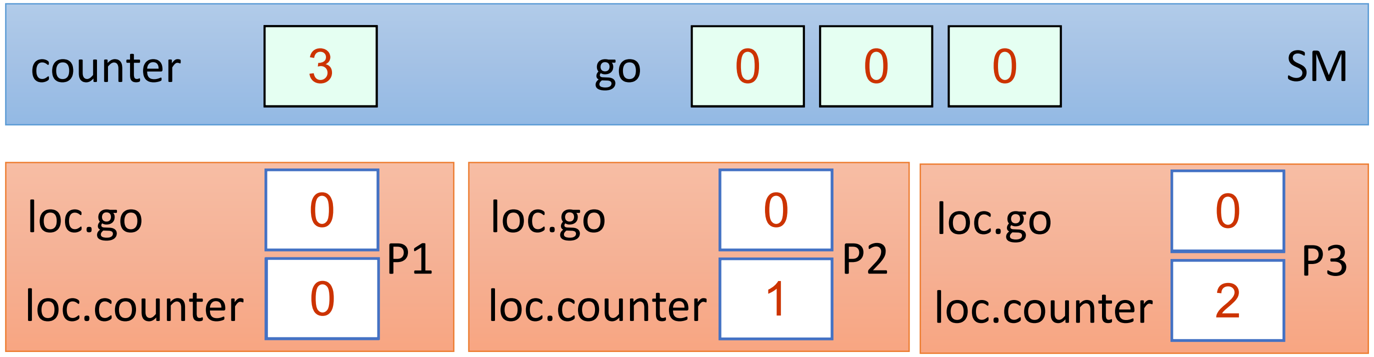
A Local Spinning Counter Barrier

Example Run for n=3 Threads



A Local Spinning Counter Barrier

Example Run for n=3 Threads

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        counter := 0
        for j=1 to n { go[j] := 1 – go[j] }
else await(local.go ≠ go[i])
```

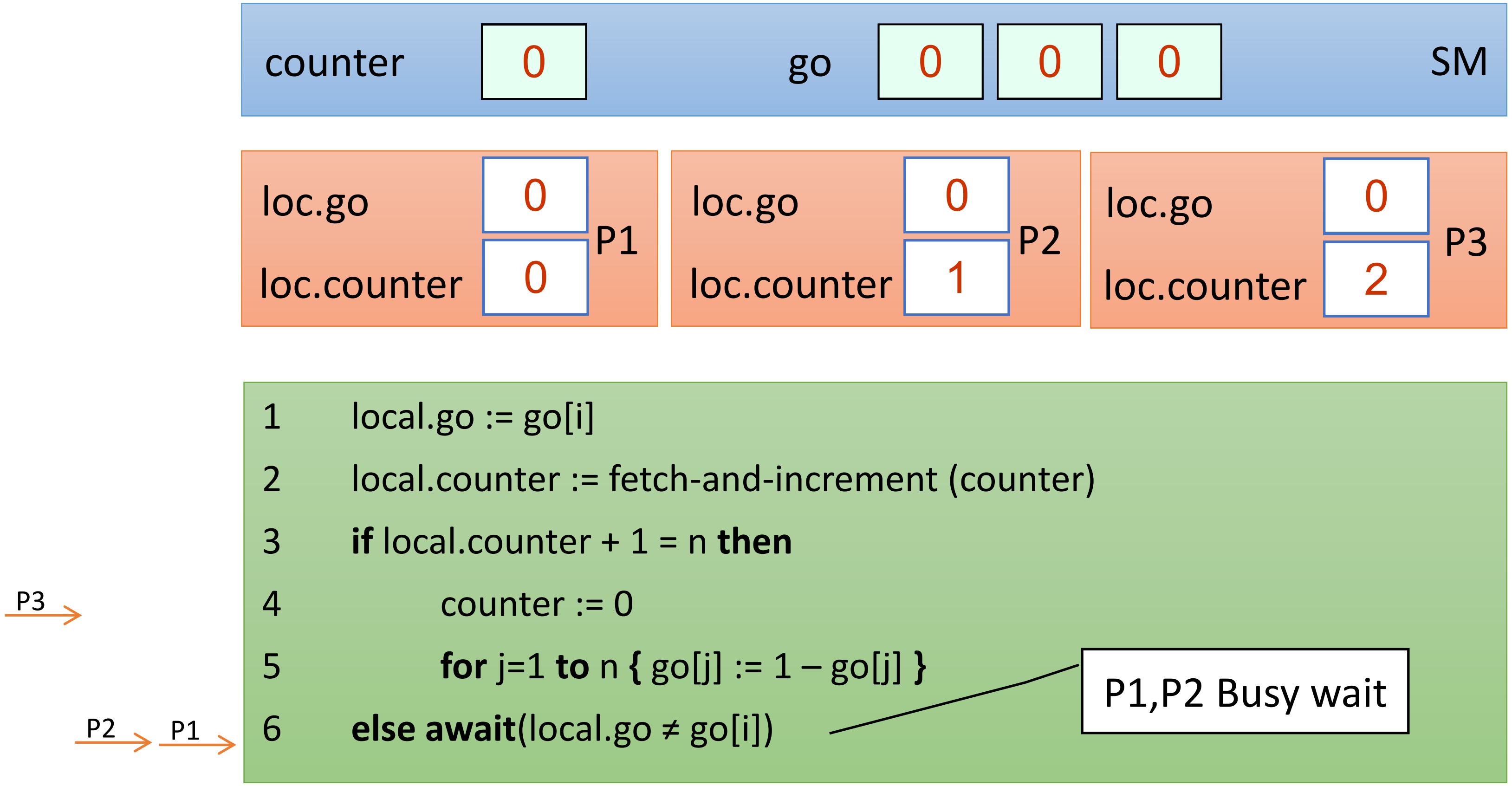
P3 → (line 4)

P2 → P1 → (line 6)

P1,P2 Busy wait

A Local Spinning Counter Barrier

Example Run for n=3 Threads



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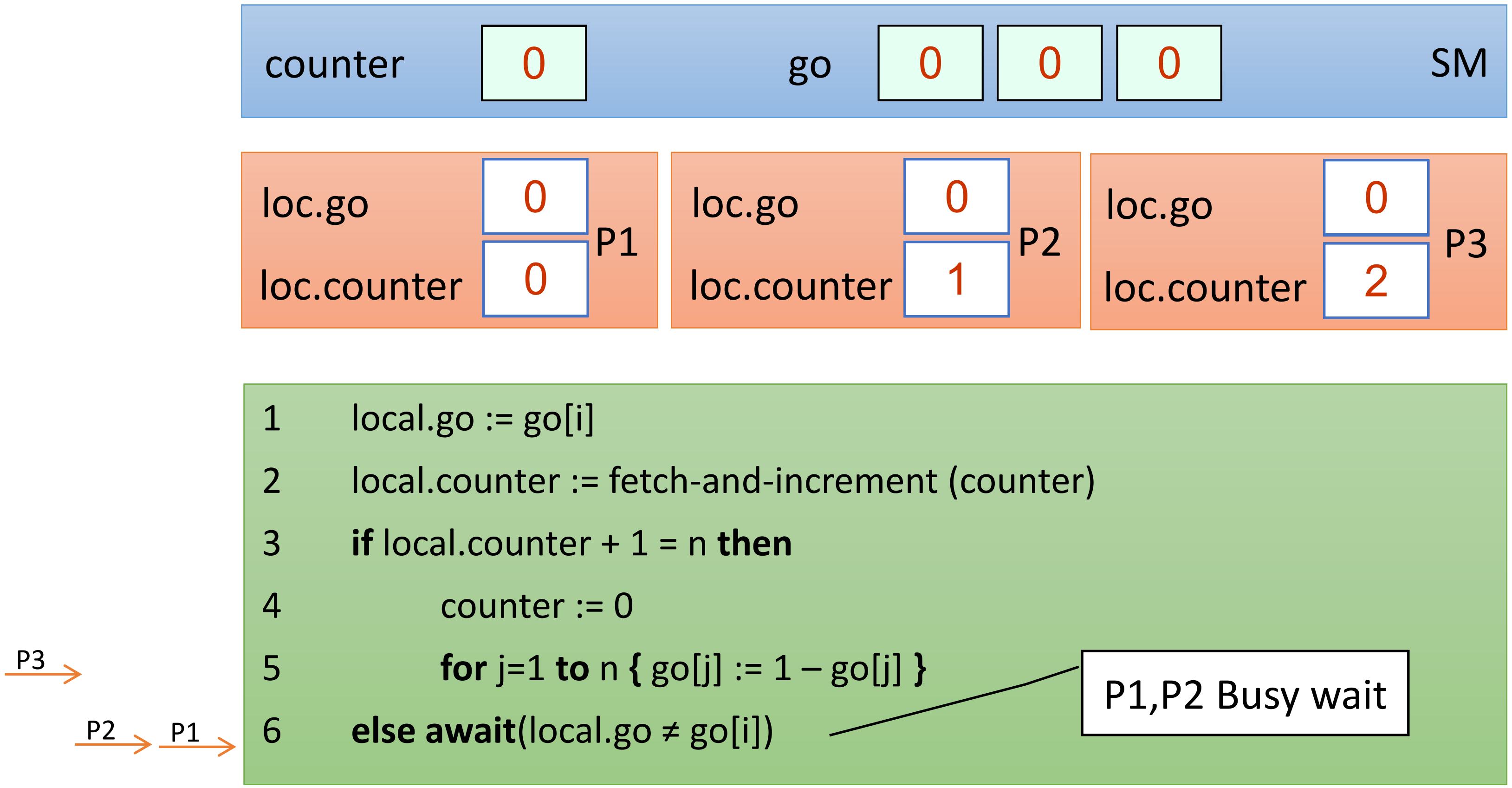

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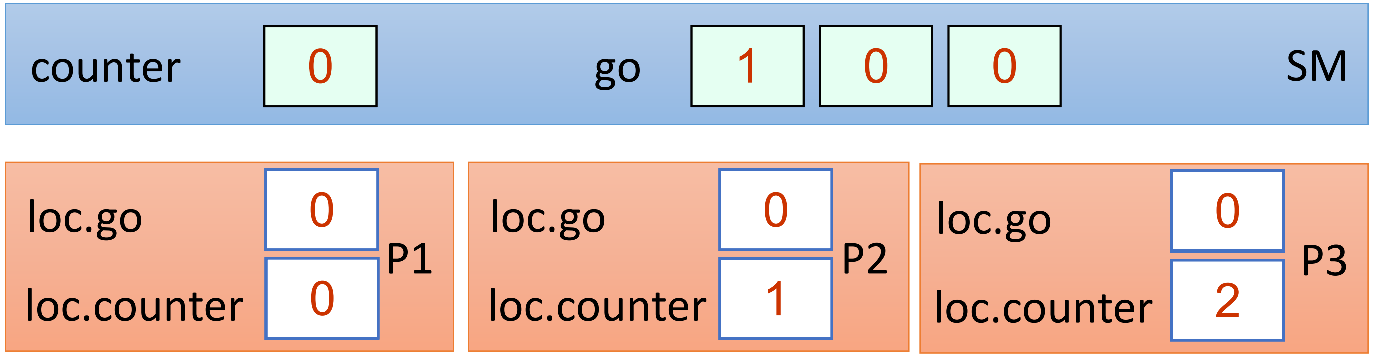


```
local.go := go[i]
local.counter := fetch-and-increment (counter)
if local.counter + 1 = n then
        counter := 0
        for j=1 to n { go[j] := 1 – go[j] }      ← P3
else await(local.go ≠ go[i])                     ← P2, P1
```

P1,P2 Busy wait

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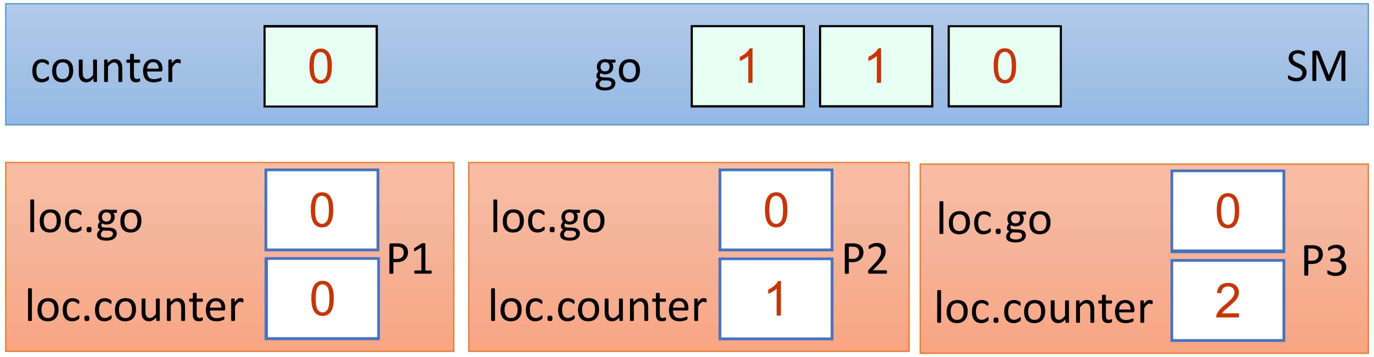


```
1    local.go := go[i]
2    local.counter := fetch-and-increment (counter)
3    if local.counter + 1 = n then
4         counter := 0
5         for j=1 to n { go[j] := 1 – go[j] }
6    else await(local.go ≠ go[i])
```

P3 → (line 5)

P2 → P1 → (line 6)

P1,P2 Busy wait

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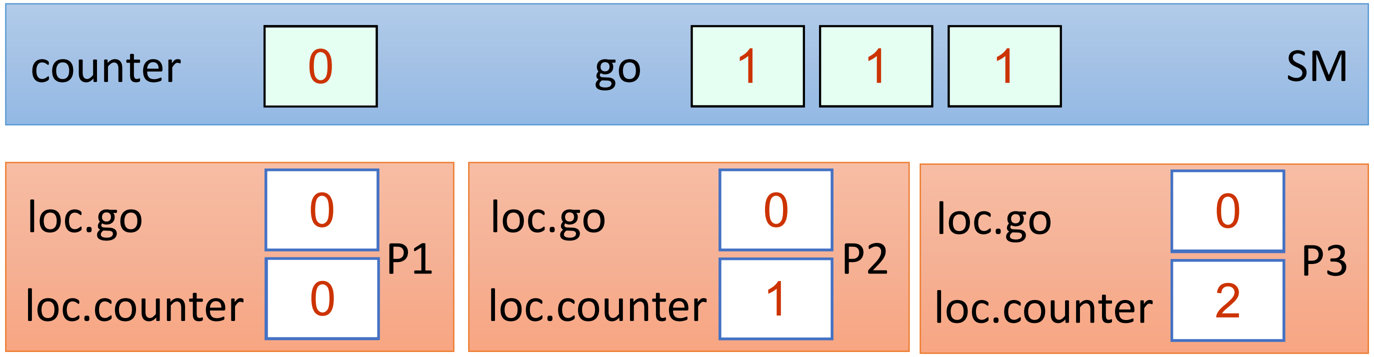


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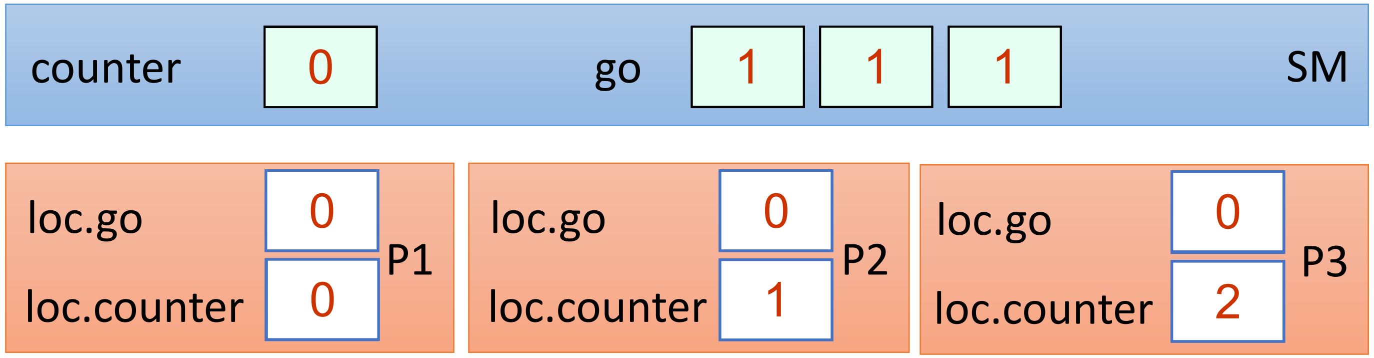
Example Run for n=3 Threads

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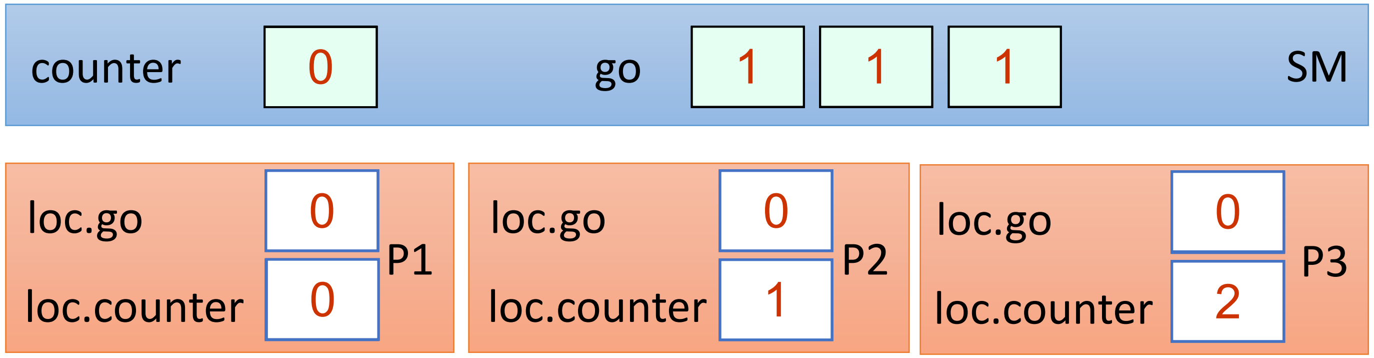
A Local Spinning Counter Barrier

Example Run for n=3 Threads

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        counter := 0
        for j=1 to n { go[j] := 1 – go[j] }
else await(local.go ≠ go[i])
```

Pros/Cons?

Does this actually reduce contention?

Comparison of counter-based Barriers

Simple Barrier

- Pros:
- Cons:

Simple Barrier with go array

- Pros:
- Cons:

Comparison of counter-based Barriers

Simple Barrier

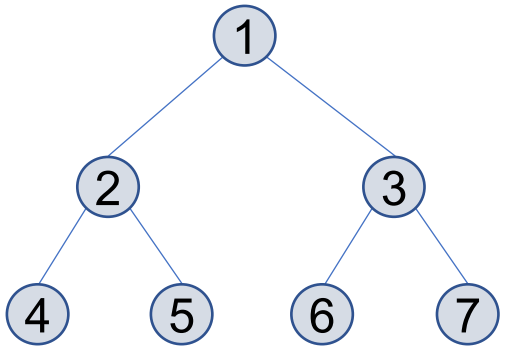
- Pros:
  - Very Simple
  - Shared memory: O(log n) ***bits***
  - Takes O(1) until last waiting p is awaken
- Cons:
  - High contention on the go bit
  - Contention on the counter register (*)

Simple Barrier with go array

- Pros:
  - Low contention on the go array
  - In some models:
    - spinning is done on local memory
    - remote mem. ref.: O(1)
- Cons:
  - Shared memory: O(n)
  - Still contention on the counter register (*)
  - Takes O(n) until last waiting p is awaken

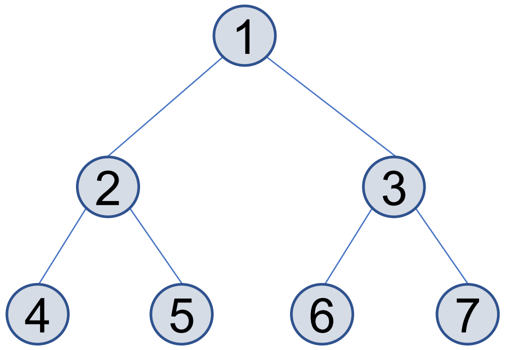
Tree Barriers

A Tree-based Barrier



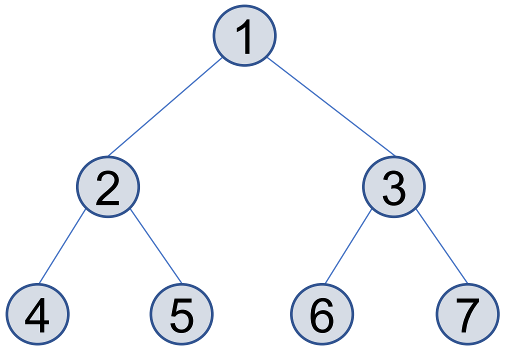
A Tree-based Barrier

- Threads are organized in a binary tree
- Each node is owned by a predetermined thread



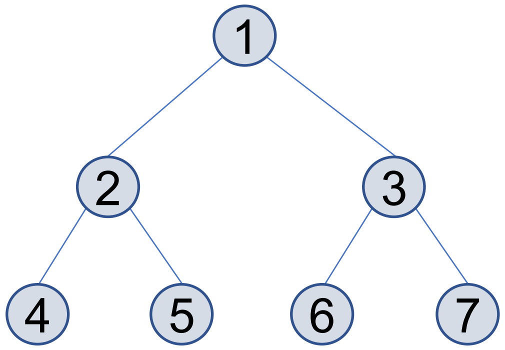
A Tree-based Barrier

- Threads are organized in a binary tree
- Each node is owned by a predetermined thread
- Each thread waits until its 2 children arrive
  - combines results
  - passes them on to its parent

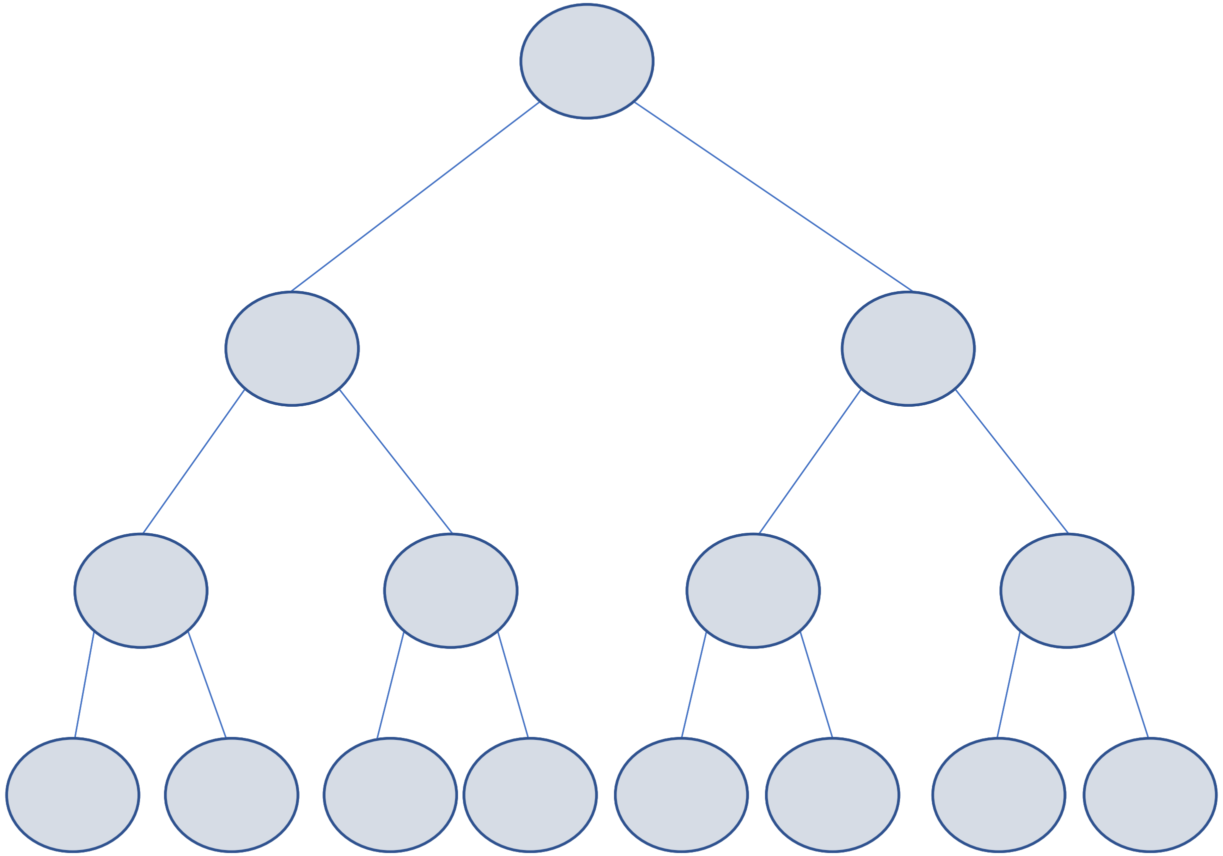


A Tree-based Barrier

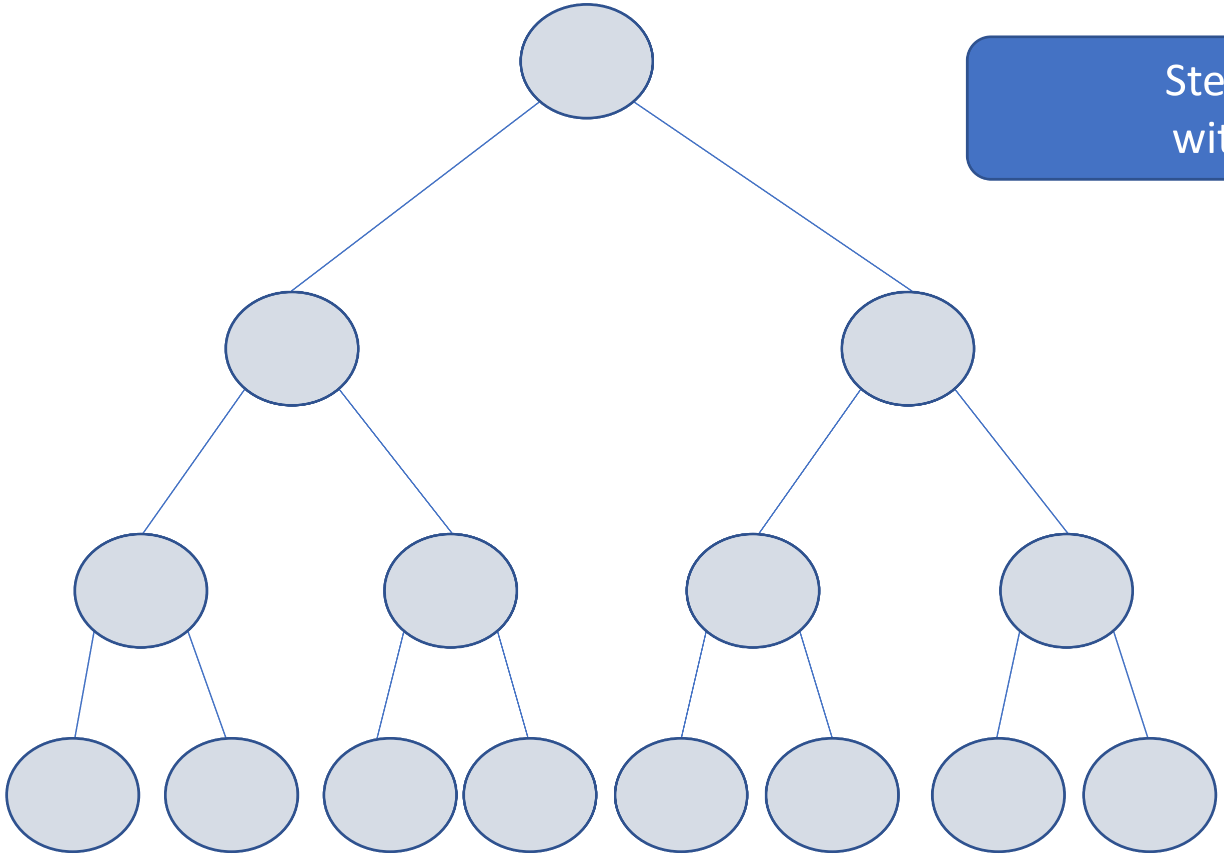
- Threads are organized in a binary tree
- Each node is owned by a predetermined thread
- Each thread waits until its 2 children arrive
  - combines results
  - passes them on to its parent
- Root learns that its 2 children have arrived→tells children they can go
- The signal propagates down the tree until all the threads get the message



A Tree-based Barrier: indexing

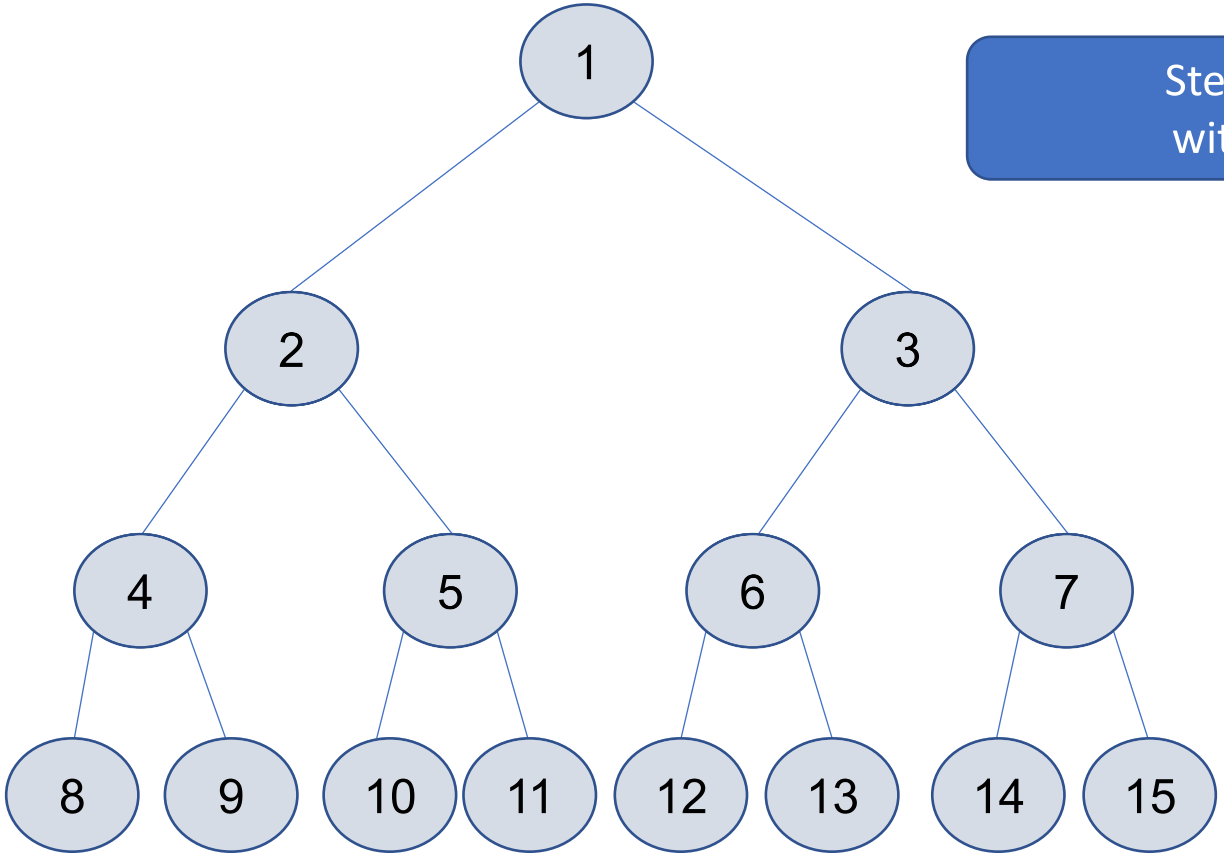


A Tree-based Barrier: indexing



Step 1: label numerically with depth-first traveral

A Tree-based Barrier: indexing

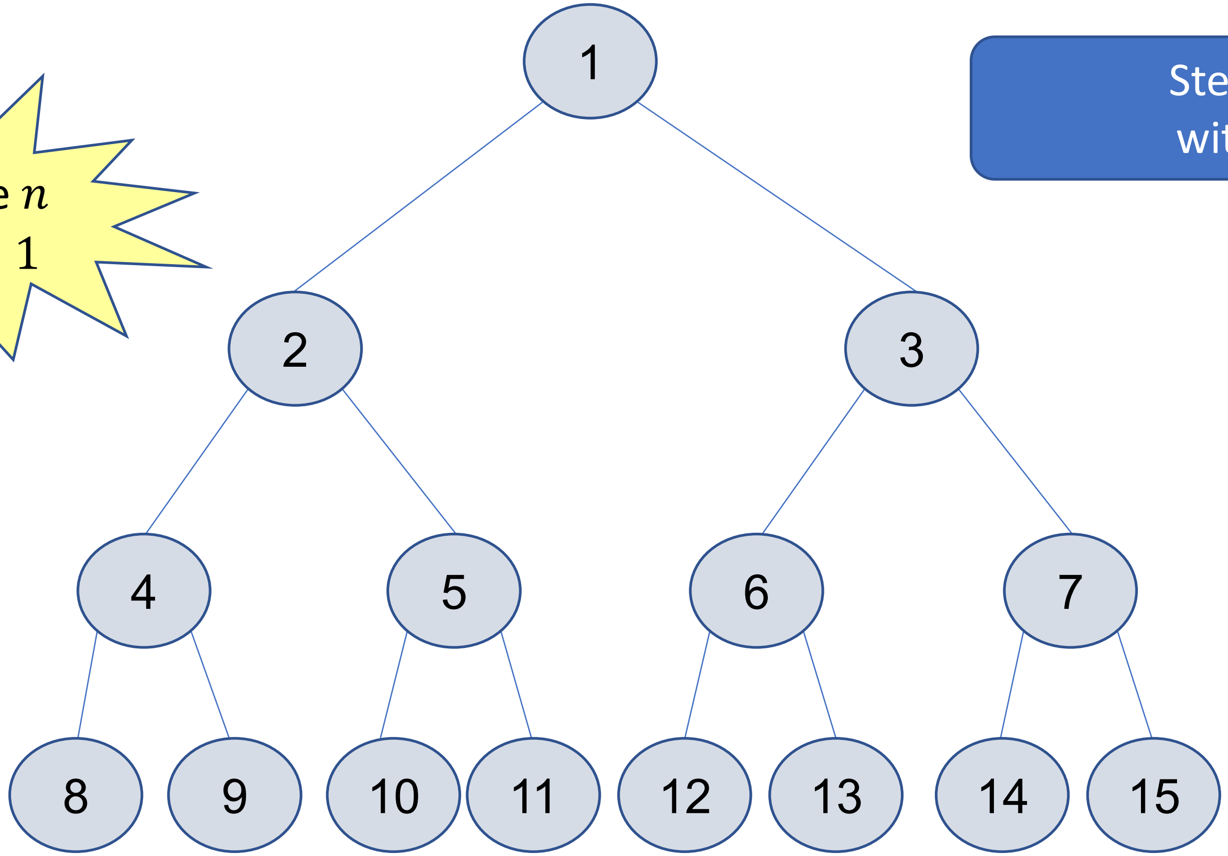


Step 1: label numerically
with depth-first traveral

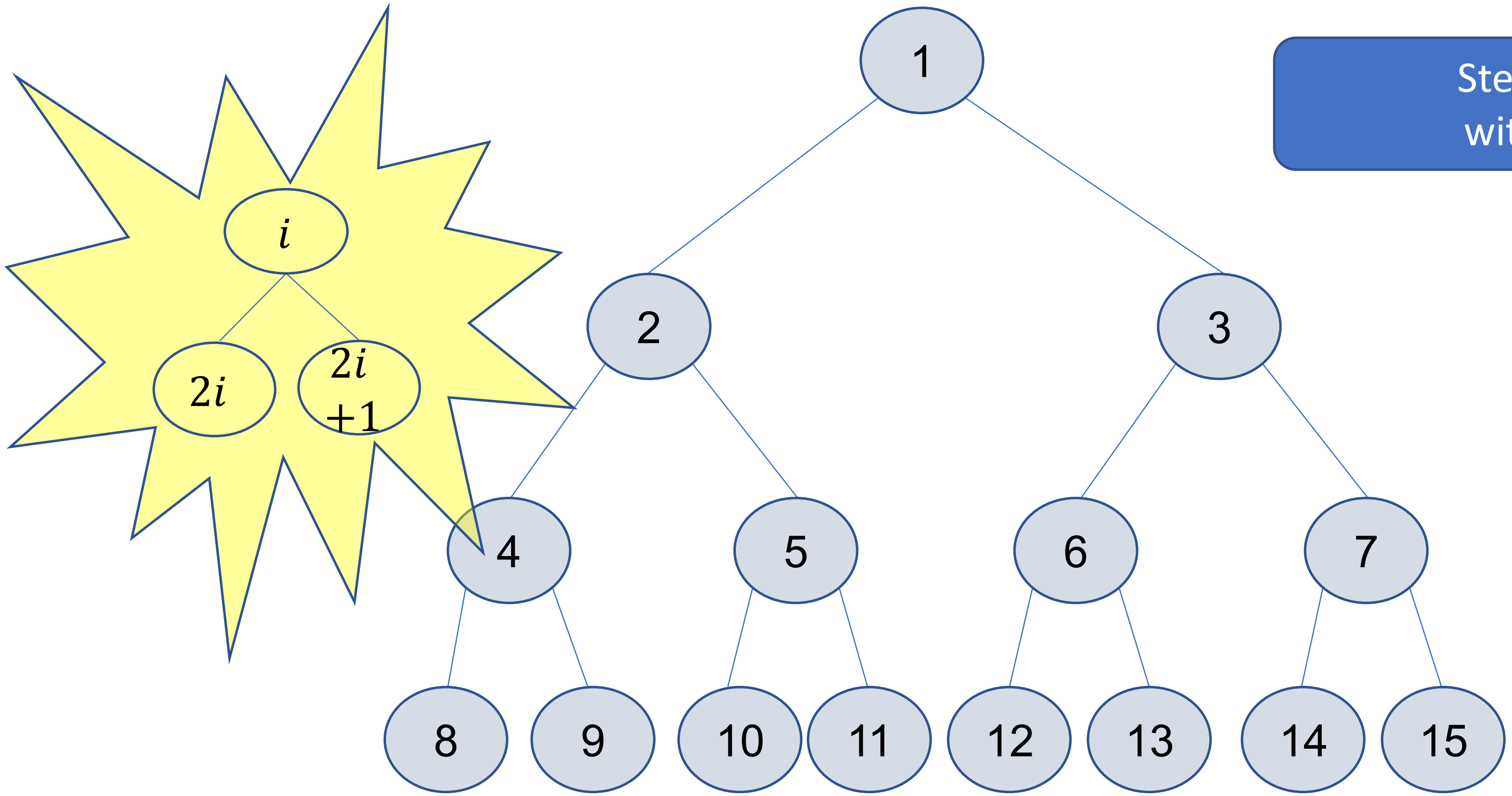
A Tree-based Barrier: indexing

Assume $n = 2^k - 1$

Step 1: label numerically with depth-first traveral



A Tree-based Barrier: indexing



Step 1: label numerically
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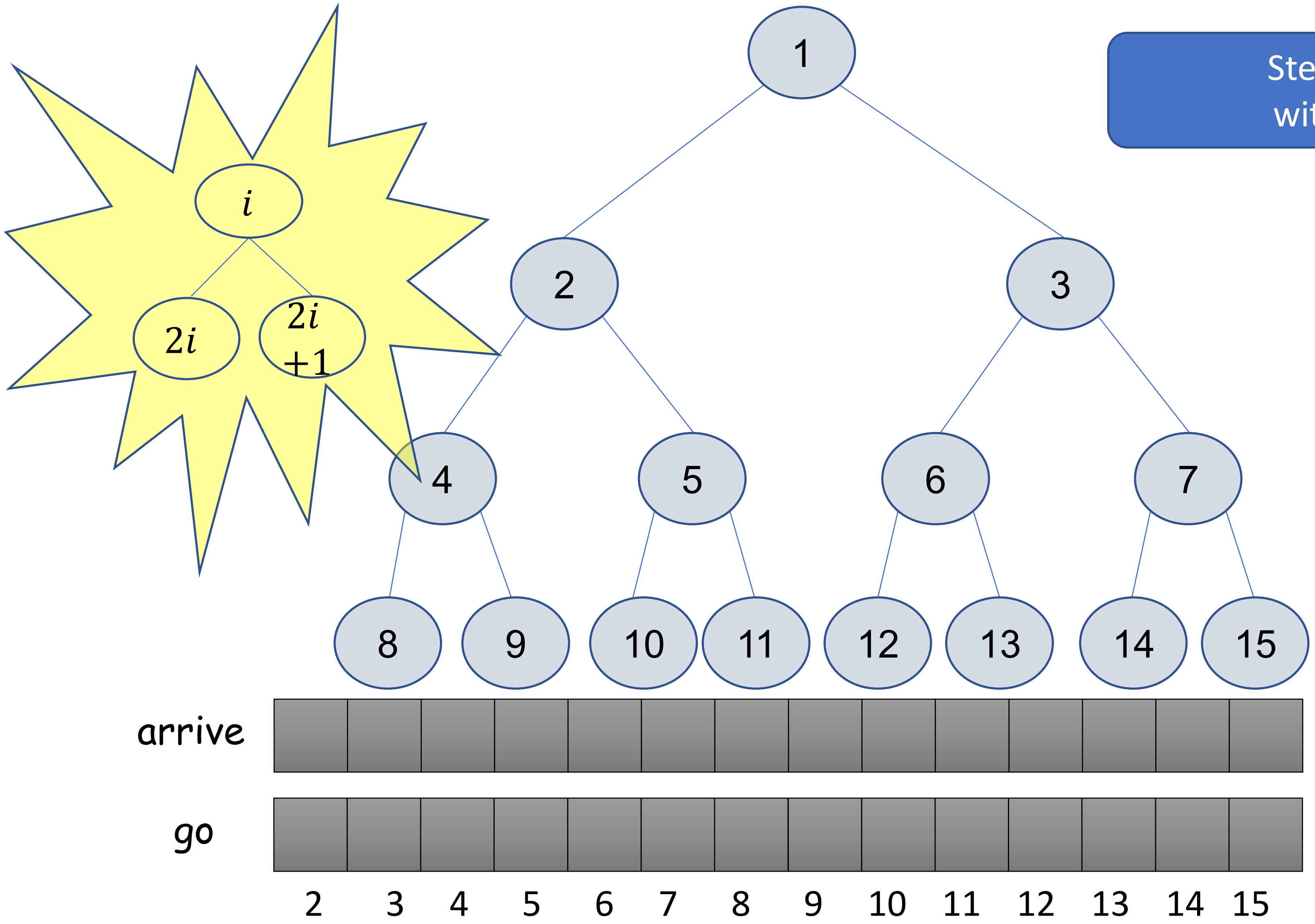
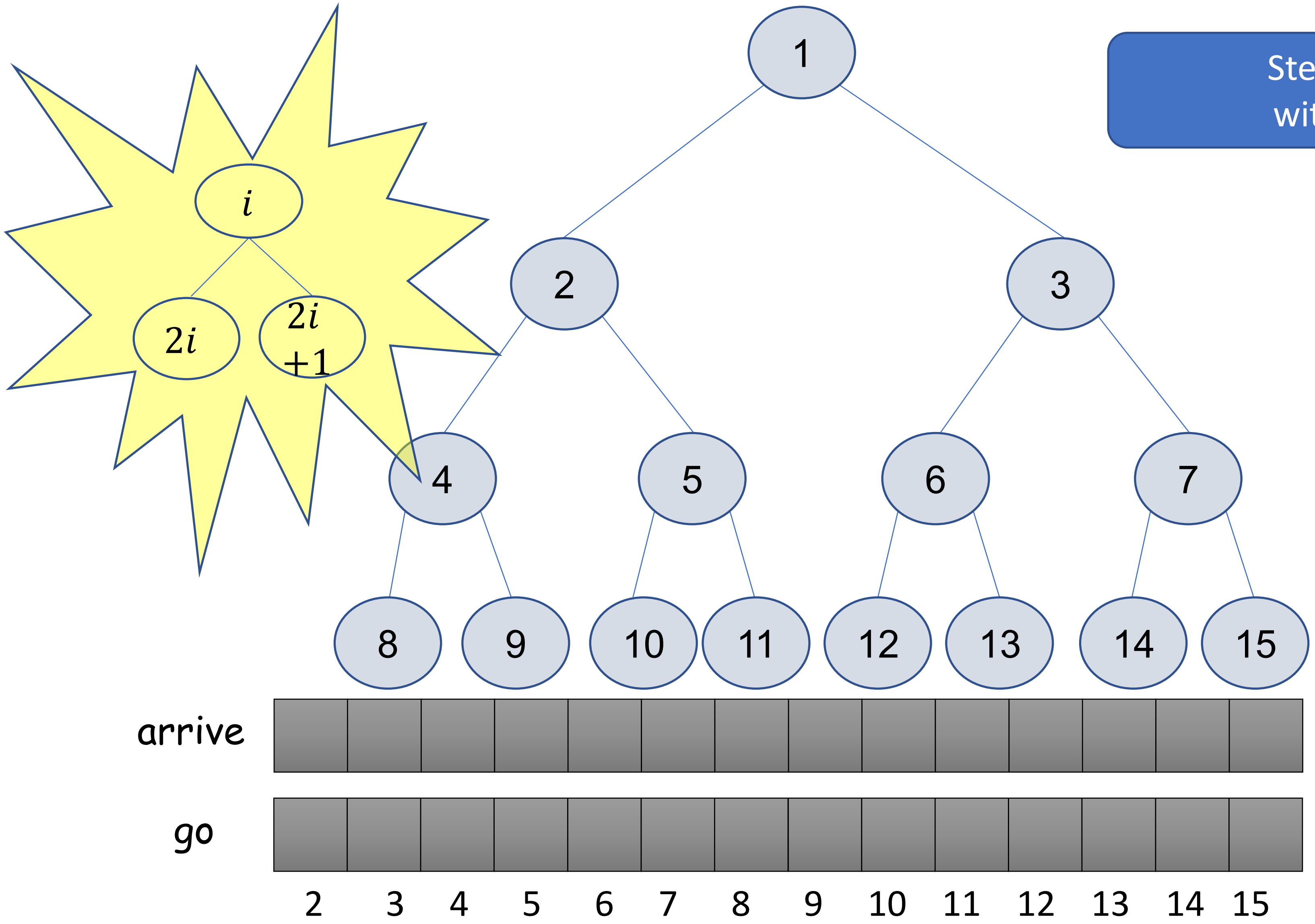
A Tree-based Barrier: indexing

Step 1: label numerically
with depth-first traveral



A Tree-based Barrier: indexing

Step 1: label numerically with depth-first traveral



Indexing starts from 2
Root → 1, doesn't need wait objects

A Tree-based Barrier
program of thread i

```
shared    arrive[2..n]: array of atomic bits, initial values = 0
          go[2..n]: array of atomic bits, initial values = 0
```

```
if i=1 then                                          // root
      await(arrive[2] = 1); arrive[2] := 0
      await(arrive[3] = 1); arrive[3] := 0
      go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                             // internal node
      await(arrive[2i] = 1); arrive[2i] := 0
      await(arrive[2i+1] = 1); arrive[2i+1] := 0
      arrive[i] := 1
      await(go[i] = 1); go[i] := 0
      go[2i] = 1; go[2i+1] := 1
else                                                 // leaf
      arrive[i] := 1
      await(go[i] = 1); go[i] := 0 fi
fi
```

A Tree-based Barrier
program of thread i

shared	arrive[2..n]: array of atomic bits, initial values = 0
	go[2..n]: array of atomic bits, initial values = 0

Root

```
if i=1 then                                        // root
        await(arrive[2] = 1); arrive[2] := 0
        await(arrive[3] = 1); arrive[3] := 0
        go[2] = 1; go[3] = 1
```

Internal

```
else if i ≤ (n-1)/2 then                           // internal node
        await(arrive[2i] = 1); arrive[2i] := 0
        await(arrive[2i+1] = 1); arrive[2i+1] := 0
        arrive[i] := 1
        await(go[i] = 1); go[i] := 0
        go[2i] = 1; go[2i+1] := 1
```

Leaf

```
else                                               // leaf
        arrive[i] := 1
        await(go[i] = 1); go[i] := 0 fi
fi
```

A Tree-based Barrier
program of thread i

shared arrive[2..n]: array of atomic bits, initial values = 0
go[2..n]: array of atomic bits, initial values = 0

Root / Internal / Leaf

```
if i=1 then                                          // root
    await(arrive[2] = 1); arrive[2] := 0
    await(arrive[3] = 1); arrive[3] := 0
    go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                             // internal node
    await(arrive[2i] = 1); arrive[2i] := 0
    await(arrive[2i+1] = 1); arrive[2i+1] := 0
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0
    go[2i] = 1; go[2i+1] := 1
else                                                 // leaf
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0 fi
fi
```

Root:
- Wait for arriving children
- Tell children to go

A Tree-based Barrier
program of thread i

```
shared   arrive[2..n]: array of atomic bits, initial values = 0
         go[2..n]: array of atomic bits, initial values = 0
```

```
if i=1 then                                         // root
    await(arrive[2] = 1); arrive[2] := 0
    await(arrive[3] = 1); arrive[3] := 0
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else if i ≤ (n-1)/2 then                            // internal node
    await(arrive[2i] = 1); arrive[2i] := 0
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    go[2i] = 1; go[2i+1] := 1
else                                                // leaf
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0 fi
fi
```

Root (lines 1–4)

Internal (lines 5–10)

Leaf (lines 11–14)

Root:
- Wait for arriving children
- Tell children to go

Internal:
- Wait for arriving children
- Tell parent about it
- Wait for parent go signal
- Tell children to go

A Tree-based Barrier

program of thread i

```
shared   arrive[2..n]: array of atomic bits, initial values = 0
         go[2..n]: array of atomic bits, initial values = 0
```

Root:

```
if i=1 then                                          // root
      await(arrive[2] = 1); arrive[2] := 0
      await(arrive[3] = 1); arrive[3] := 0
      go[2] = 1; go[3] = 1
```

Internal:

```
else if i ≤ (n-1)/2 then                             // internal node
      await(arrive[2i] = 1); arrive[2i] := 0
      await(arrive[2i+1] = 1); arrive[2i+1] := 0
      arrive[i] := 1
      await(go[i] = 1); go[i] := 0
      go[2i] = 1; go[2i+1] := 1
```

Leaf:

```
else                                                 // le
      arrive[i] := 1
      await(go[i] = 1); go[i] := 0 fi
fi
```

Root:
- Wait for arriving children
- Tell children to go

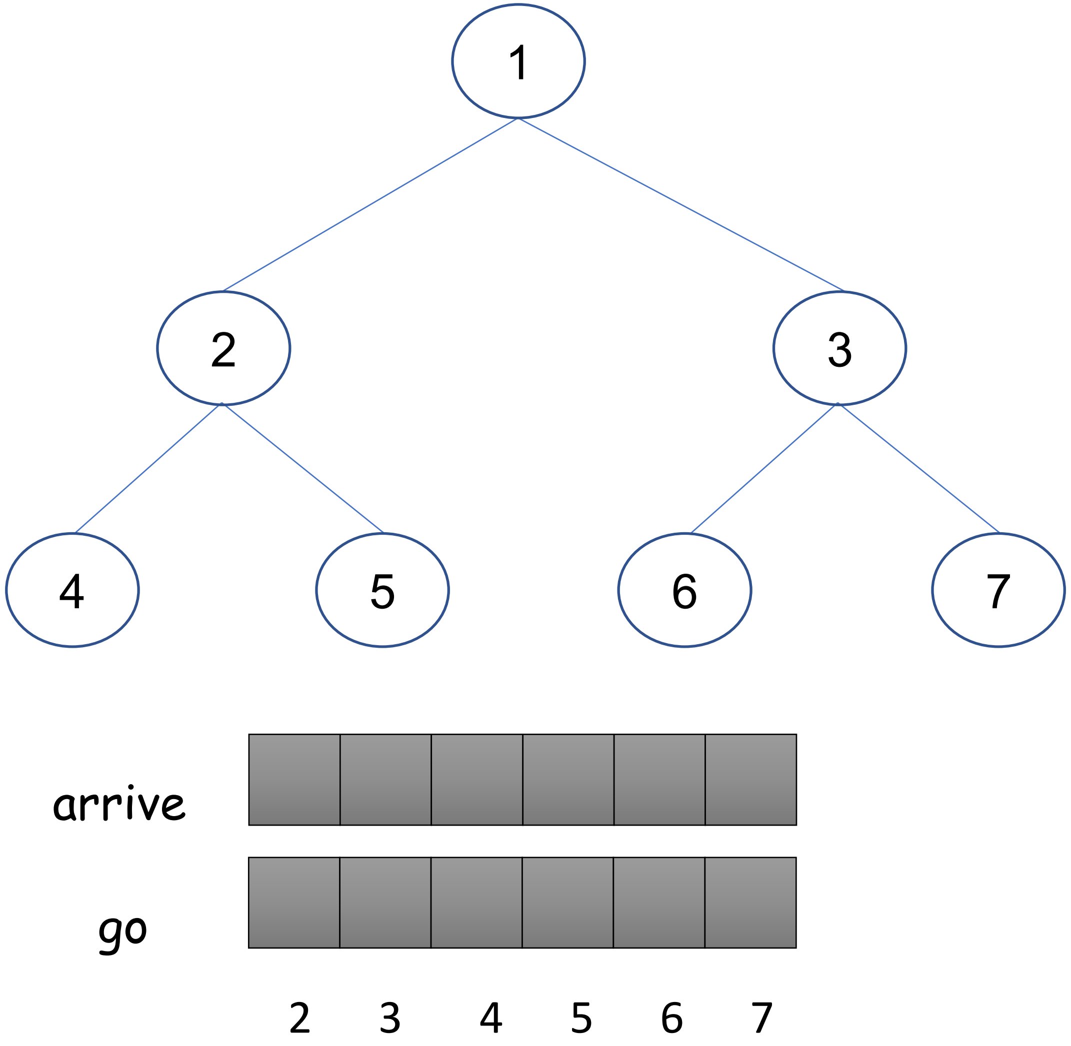
Internal:
- Wait for arriving children
- Tell parent about it
- Wait for parent go signal
- Tell children to go

Child:
- arrive
- Wait for parent go signal

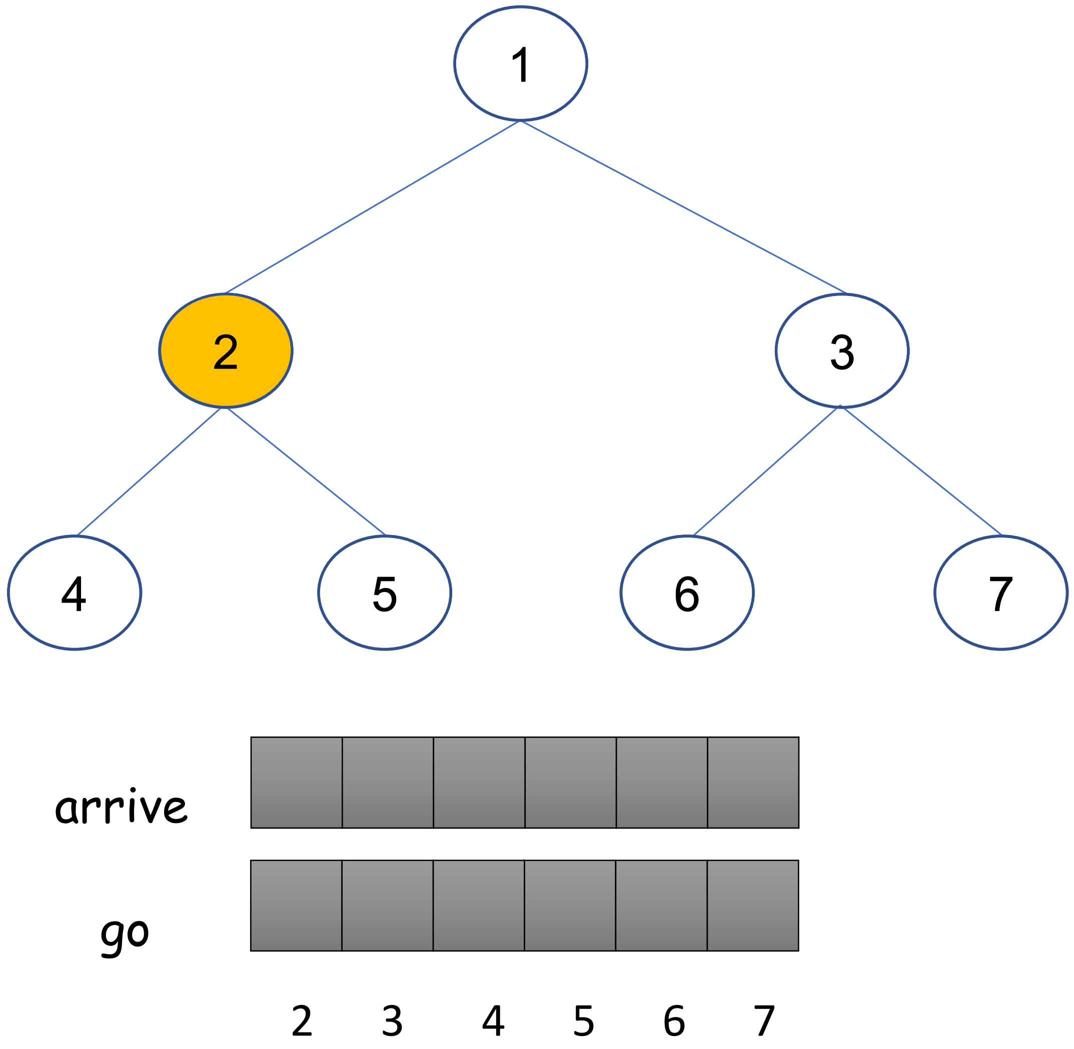
A Tree-based Barrier
Example Run for n=7 threads

```
shared   arrive[2..n]: array of atomic bits, initial values = 0
         go[2..n]: array of atomic bits, initial values = 0
```

```
if i=1 then                                         // root
    await(arrive[2] = 1); arrive[2] := 0
    await(arrive[3] = 1); arrive[3] := 0
    go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                            // internal node
    await(arrive[2i] = 1); arrive[2i] := 0
    await(arrive[2i+1] = 1); arrive[2i+1] := 0
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0
    go[2i] = 1; go[2i+1] := 1
else                                                // leaf
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0 fi
fi
```



A Tree-based Barrier
Example Run for n=7 threads



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else                                                // leaf
        arrive[i] := 1
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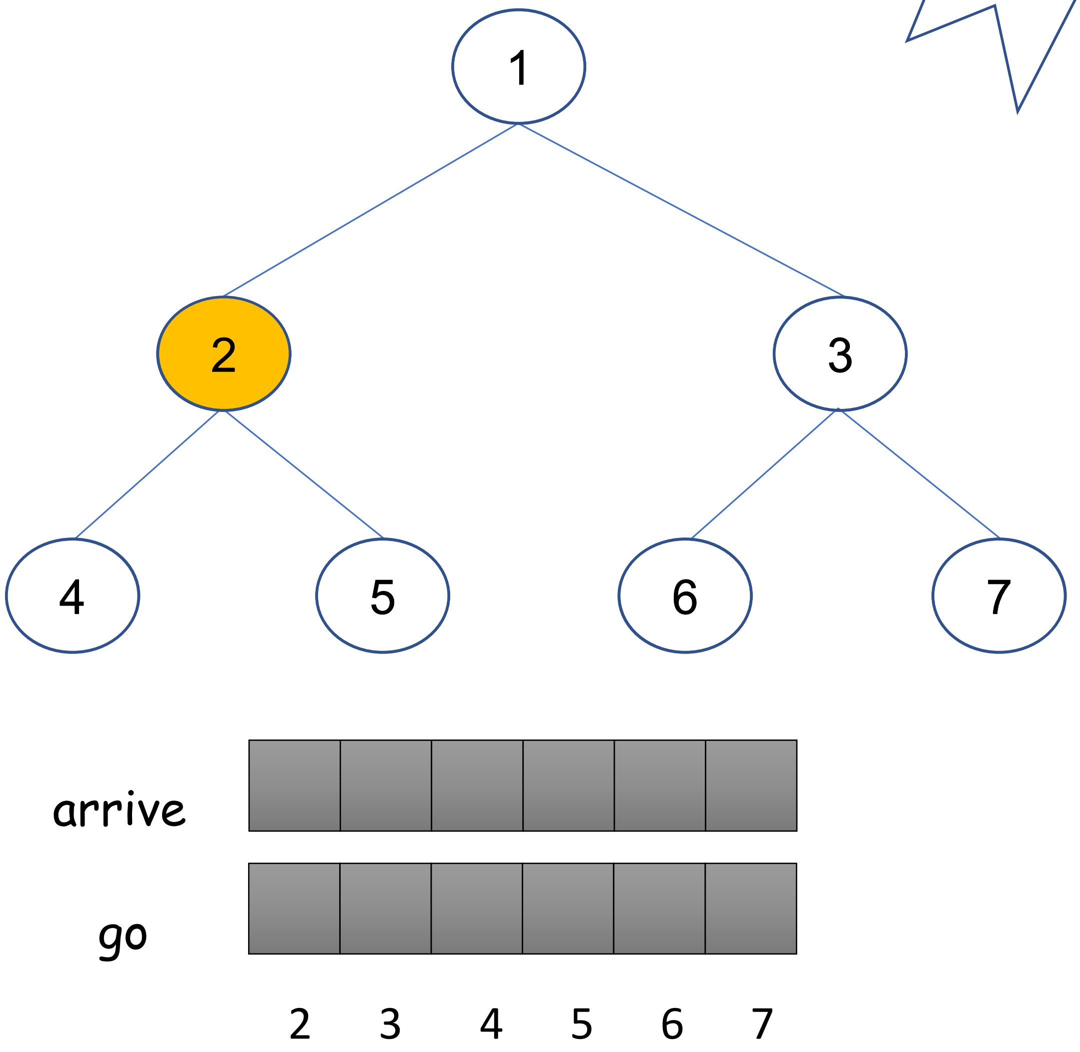
A Tree-based Barrier
Example Run for n=7 threads

arrive[2]=1 ?

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     go[2i] = 1; go[2i+1] := 1
else                                               // leaf
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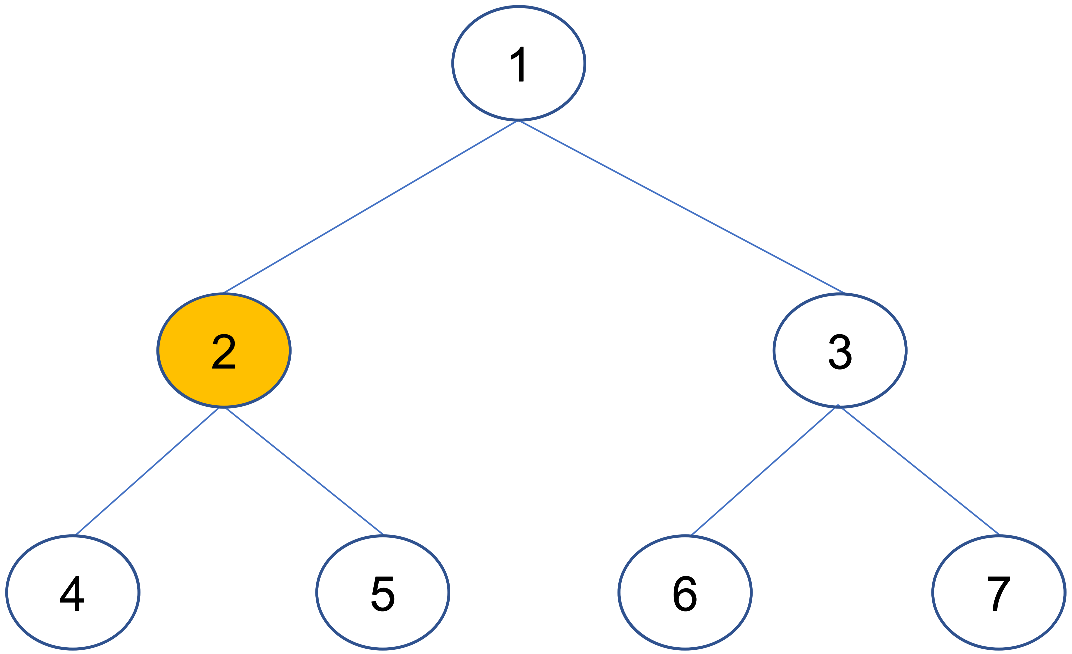
A Tree-based Barrier
Example Run for n=7 threads

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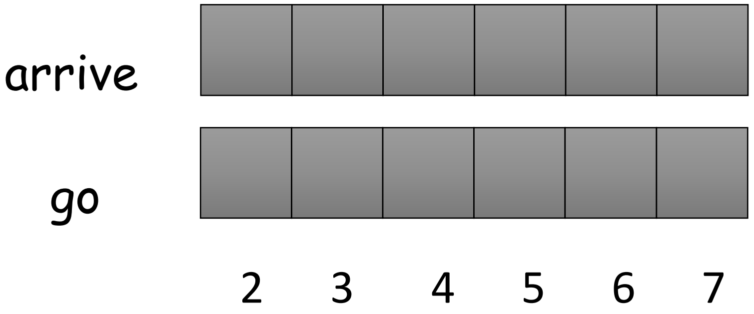
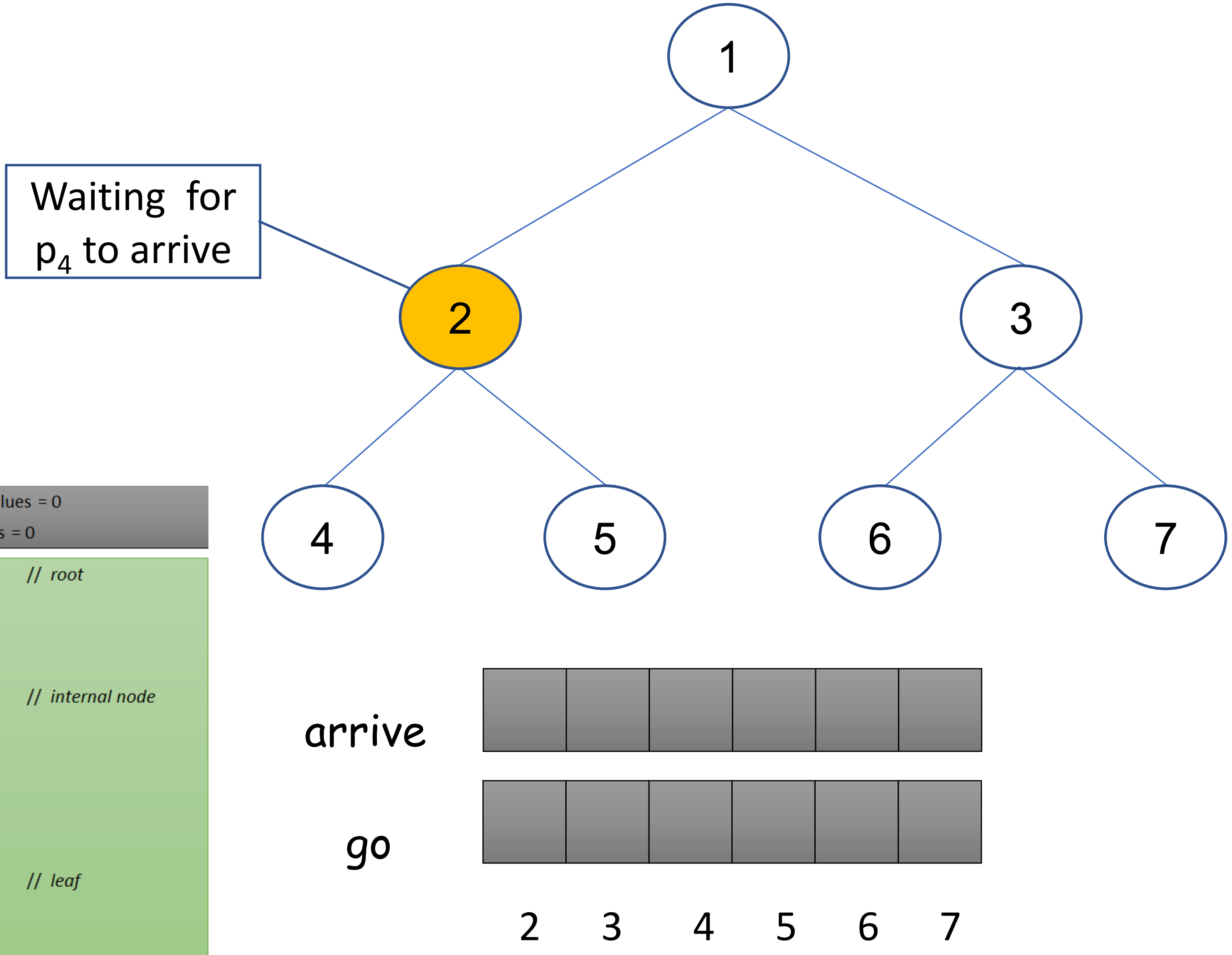


A Tree-based Barrier
Example Run for n=7 threads

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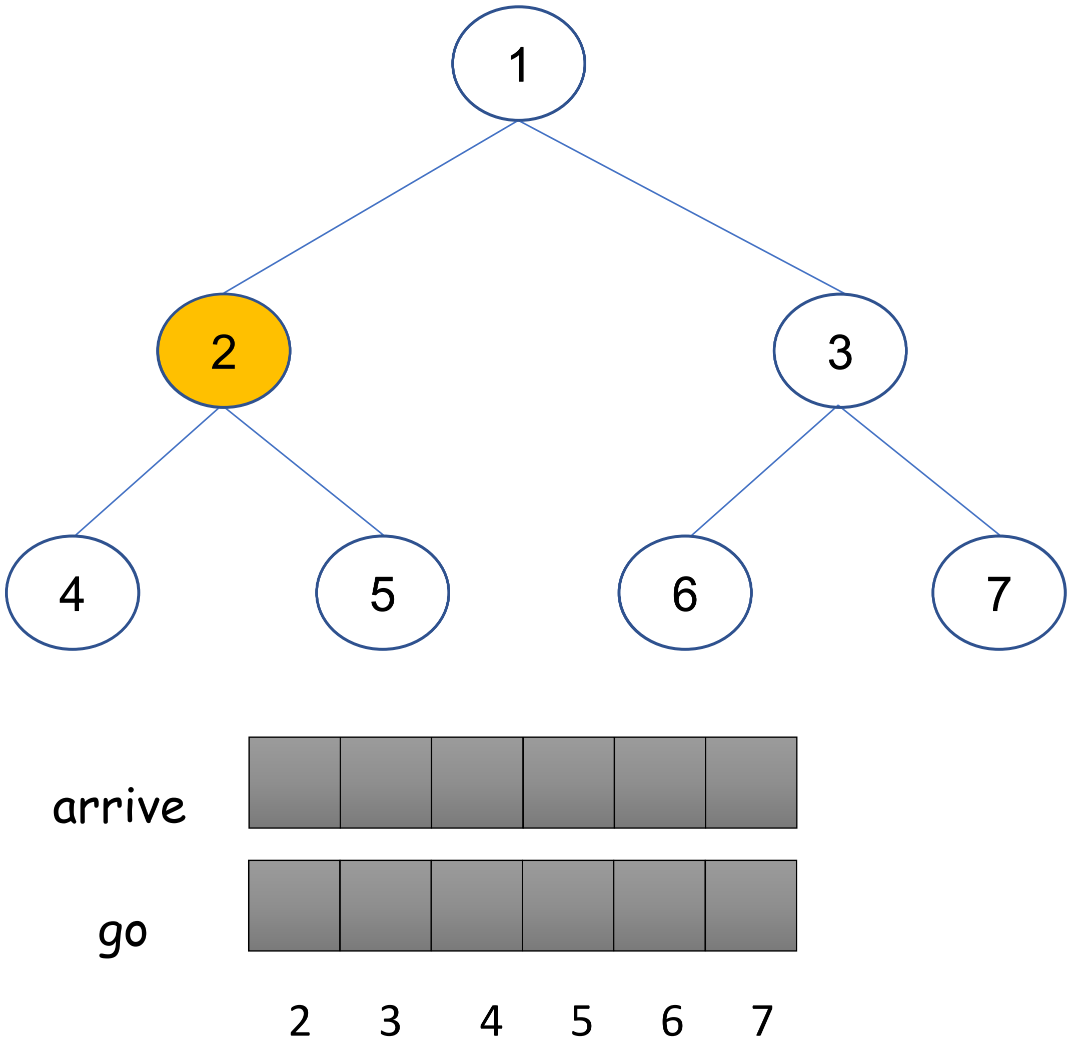
A Tree-based Barrier
Example Run for n=7 threads

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      go[2i] = 1; go[2i+1] := 1
else                                                 // leaf
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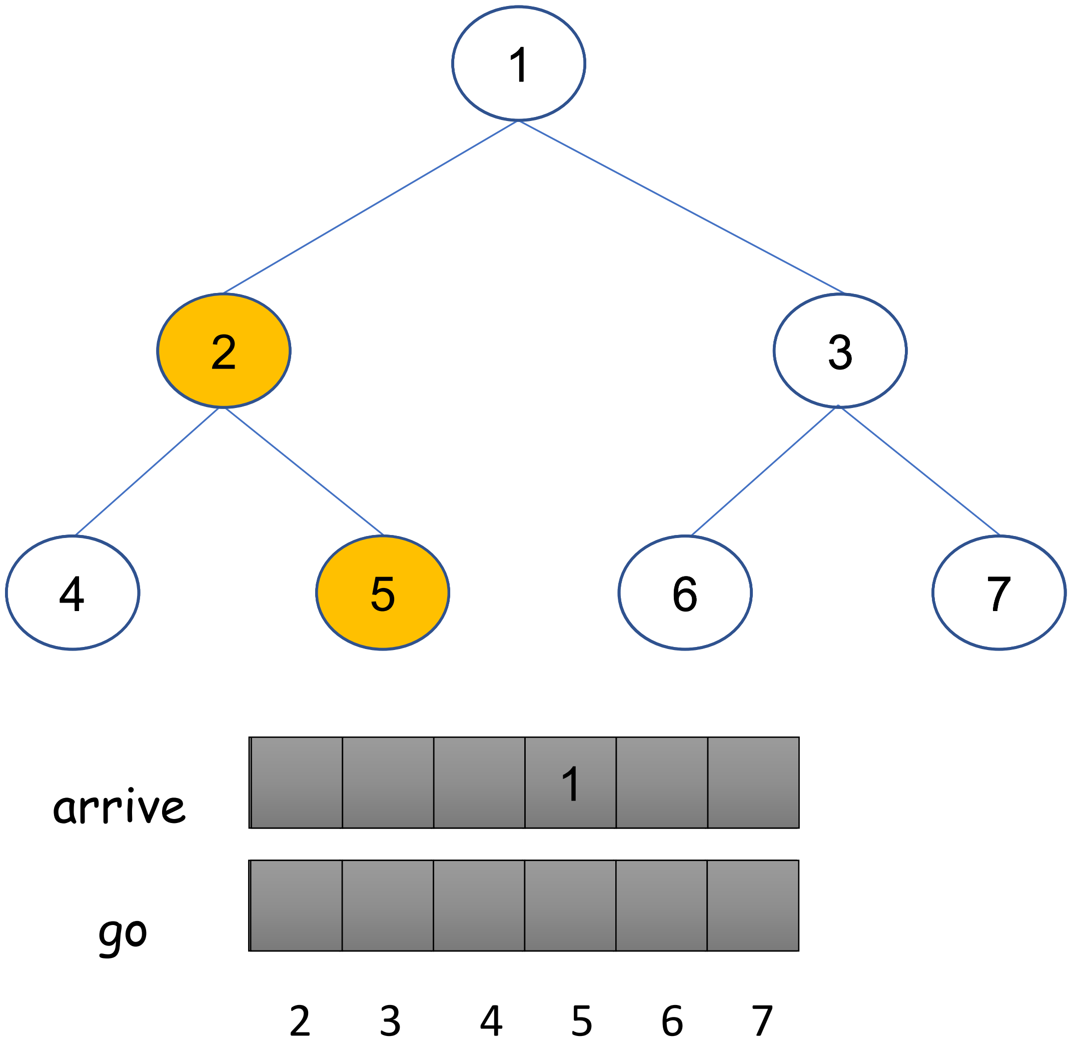
A Tree-based Barrier
Example Run for n=7 threads



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go[2..n]: array of atomic bits, initial values = 0

```
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        arrive[i] := 1
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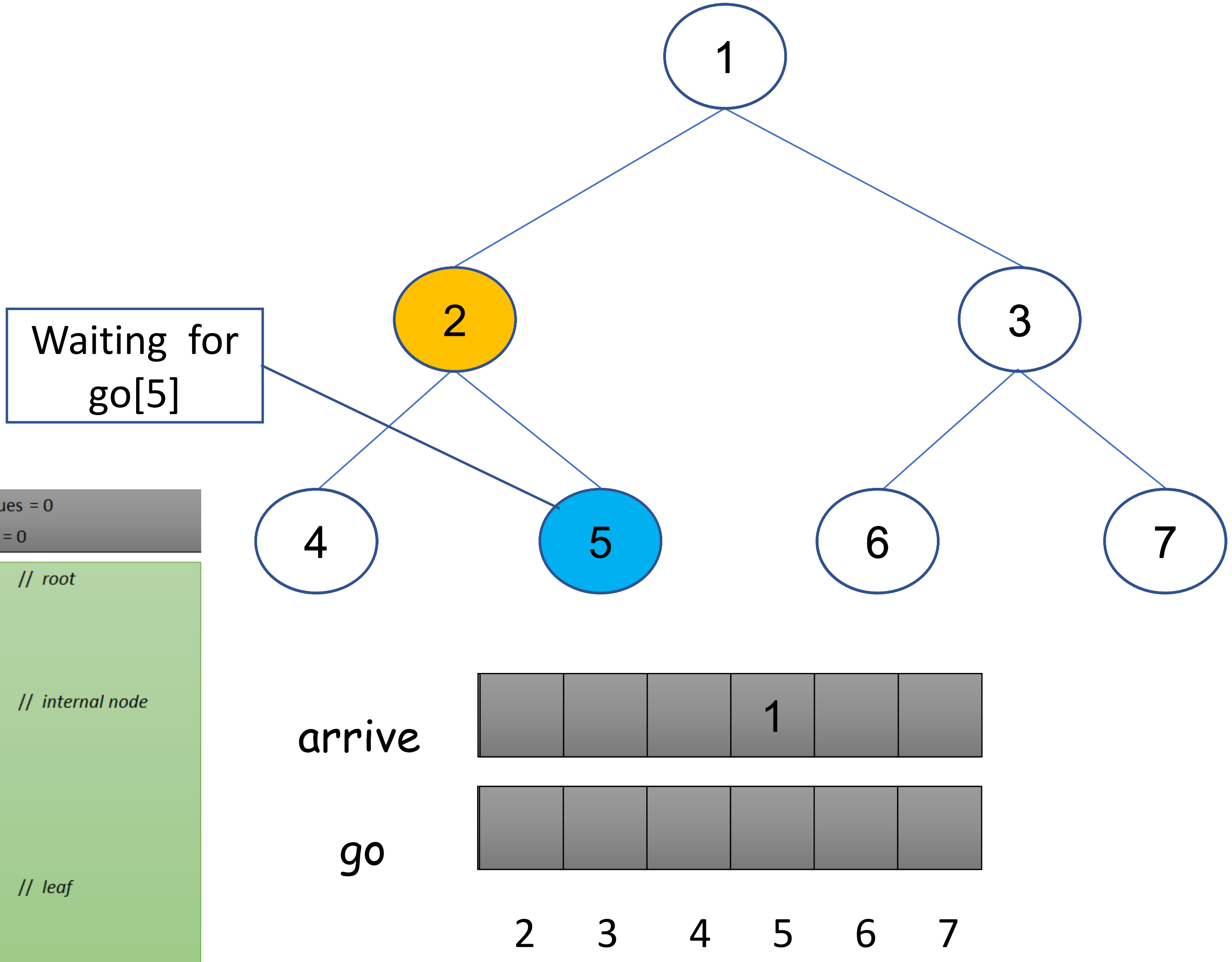
A Tree-based Barrier
Example Run for n=7 threads

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shared      arrive[2..n]: array of atomic bits, initial values = 0
            go[2..n]: array of atomic bits, initial values = 0
```

```
if i=1 then                                              // root
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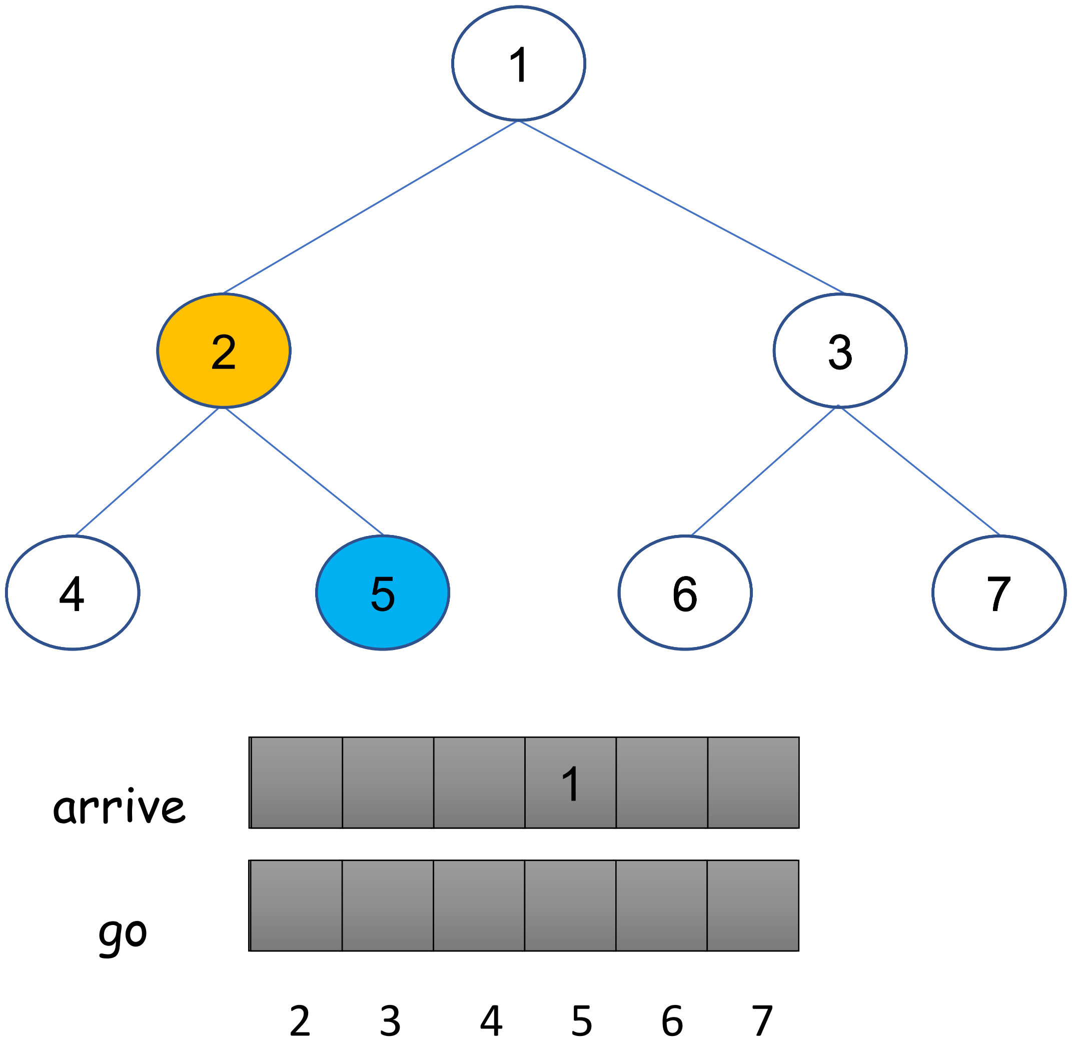
      await(arrive[3] = 1); arrive[3] := 0
      go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                                 // internal node
      await(arrive[2i] = 1); arrive[2i] := 0
      await(arrive[2i+1] = 1); arrive[2i+1] := 0
      arrive[i] := 1
      await(go[i] = 1); go[i] := 0
      go[2i] = 1; go[2i+1] := 1
else                                                     // leaf
      arrive[i] := 1
      await(go[i] = 1); go[i] := 0 fi
fi
```

A Tree-based Barrier
Example Run for n=7 threads

```
shared   arrive[2..n]: array of atomic bits, initial values = 0
         go[2..n]: array of atomic bits, initial values = 0
```

```
if i=1 then                                        // root
    await(arrive[2] = 1); arrive[2] := 0
    await(arrive[3] = 1); arrive[3] := 0
    go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                           // internal node
    await(arrive[2i] = 1); arrive[2i] := 0
    await(arrive[2i+1] = 1); arrive[2i+1] := 0
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0
    go[2i] = 1; go[2i+1] := 1
else                                               // leaf
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0 fi
fi
```



A Tree-based Barrier
Example Run for n=7 threads

```
shared   arrive[2..n]:  array of atomic bits, initial values = 0
         go[2..n]: array of atomic bits, initial values = 0

if i=1 then                                          // root
      await(arrive[2]  = 1); arrive[2]  := 0
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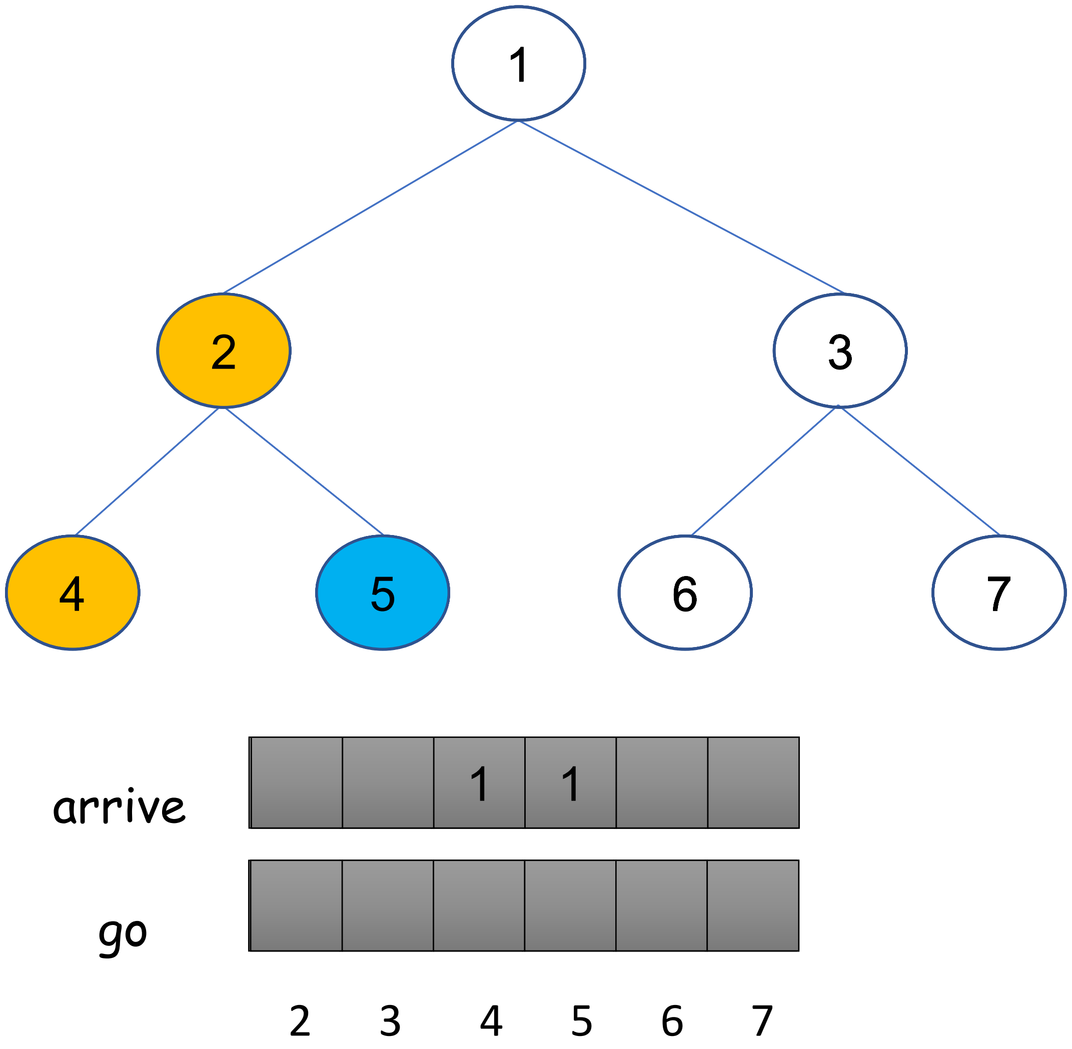
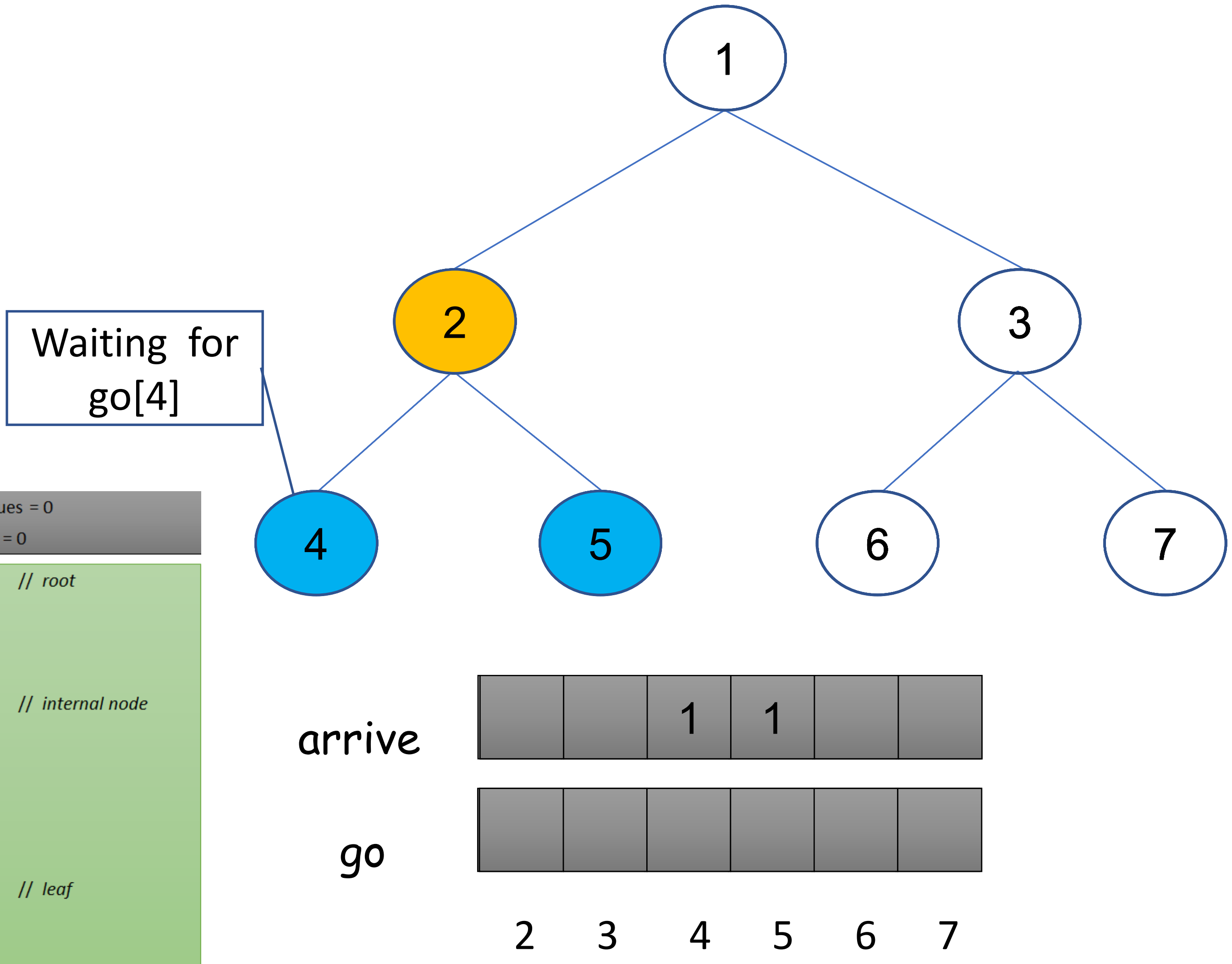
      arrive[i]  := 1
      await(go[i] = 1); go[i] := 0
      go[2i] = 1; go[2i+1] := 1
else                                                 // leaf
      arrive[i]  := 1
      await(go[i] = 1); go[i] := 0 fi
fi
```



A Tree-based Barrier
Example Run for n=7 threads



shared arrive[2..n]: array of atomic bits, initial values = 0
go[2..n]: array of atomic bits, initial values = 0

```
if i=1 then                                  // root
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    await(go[i] = 1); go[i] := 0
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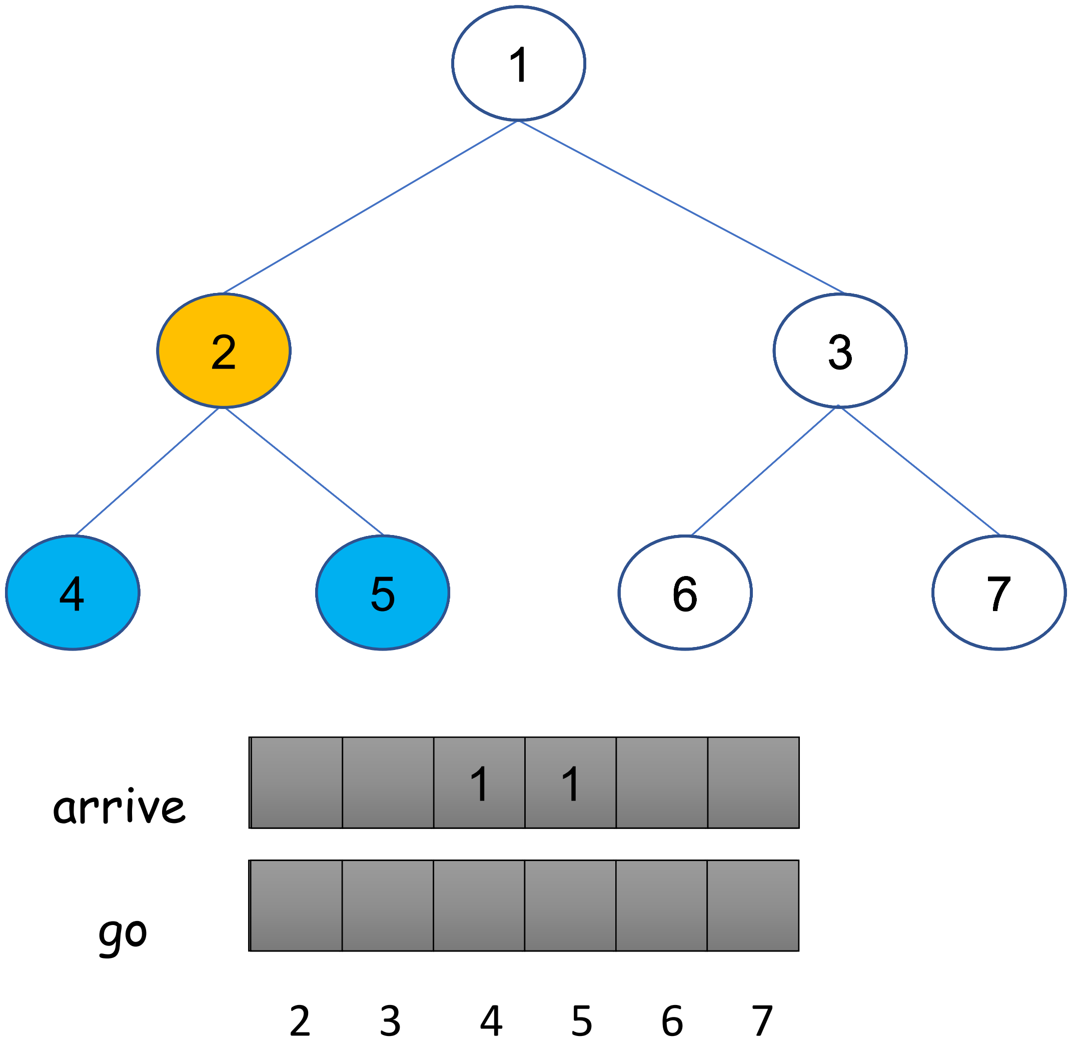
fi
```

A Tree-based Barrier
Example Run for n=7 threads




```
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```

```
if i=1 then                                          // root
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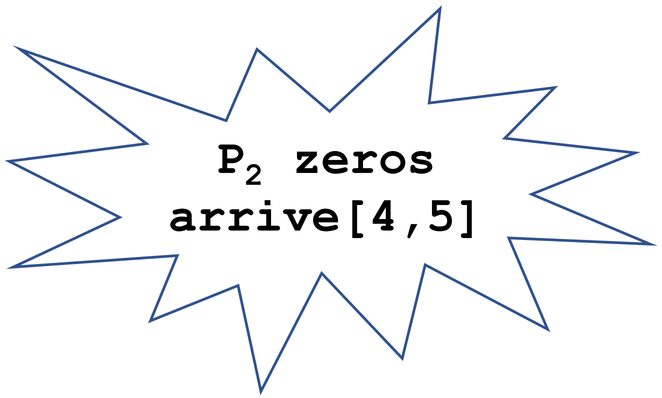
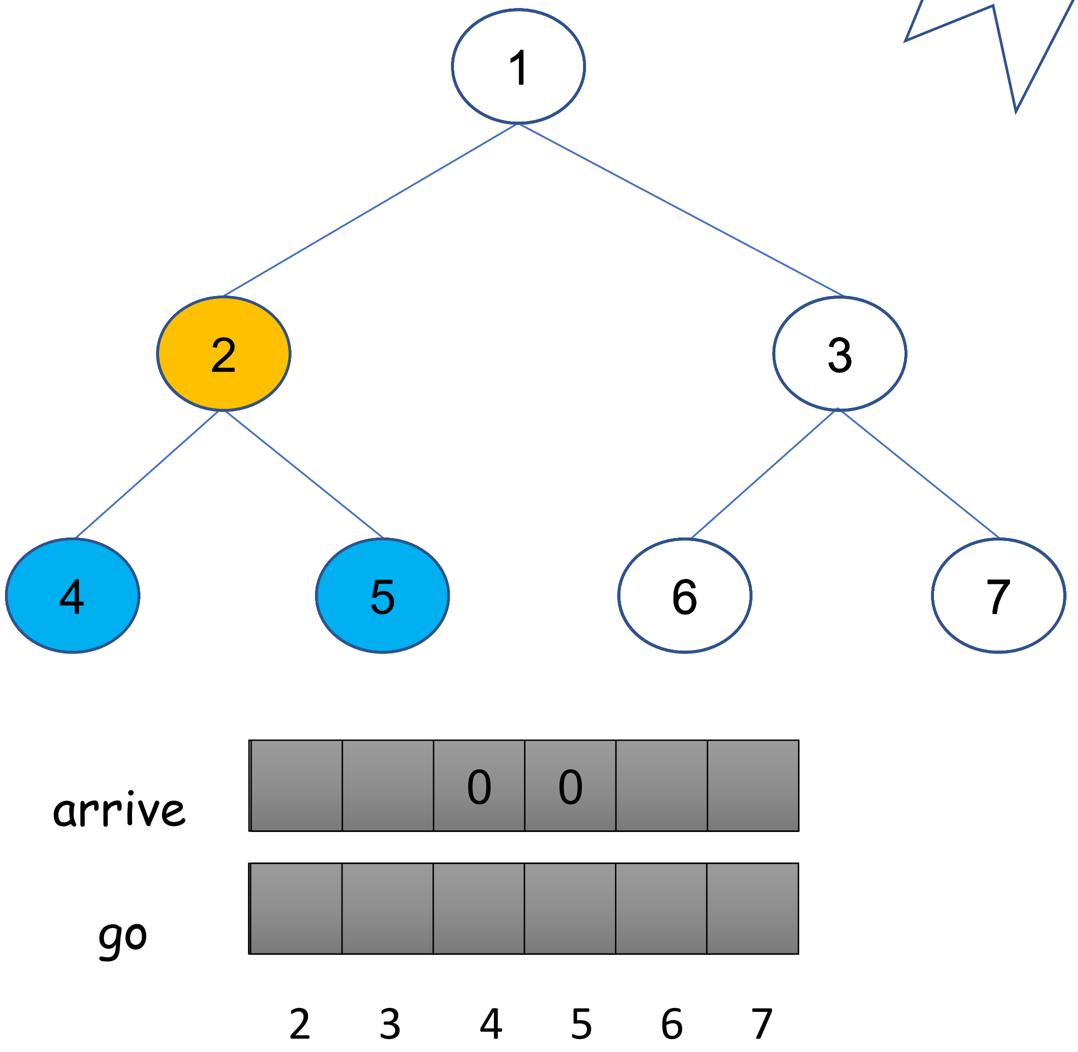
A Tree-based Barrier
Example Run for n=7 threads





shared	arrive[2..n]: array of atomic bits, initial values = 0
	go[2..n]: array of atomic bits, initial values = 0

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if i=1 then                                      // root
    await(arrive[2] = 1); arrive[2] := 0
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A Tree-based Barrier
Example Run for n=7 threads

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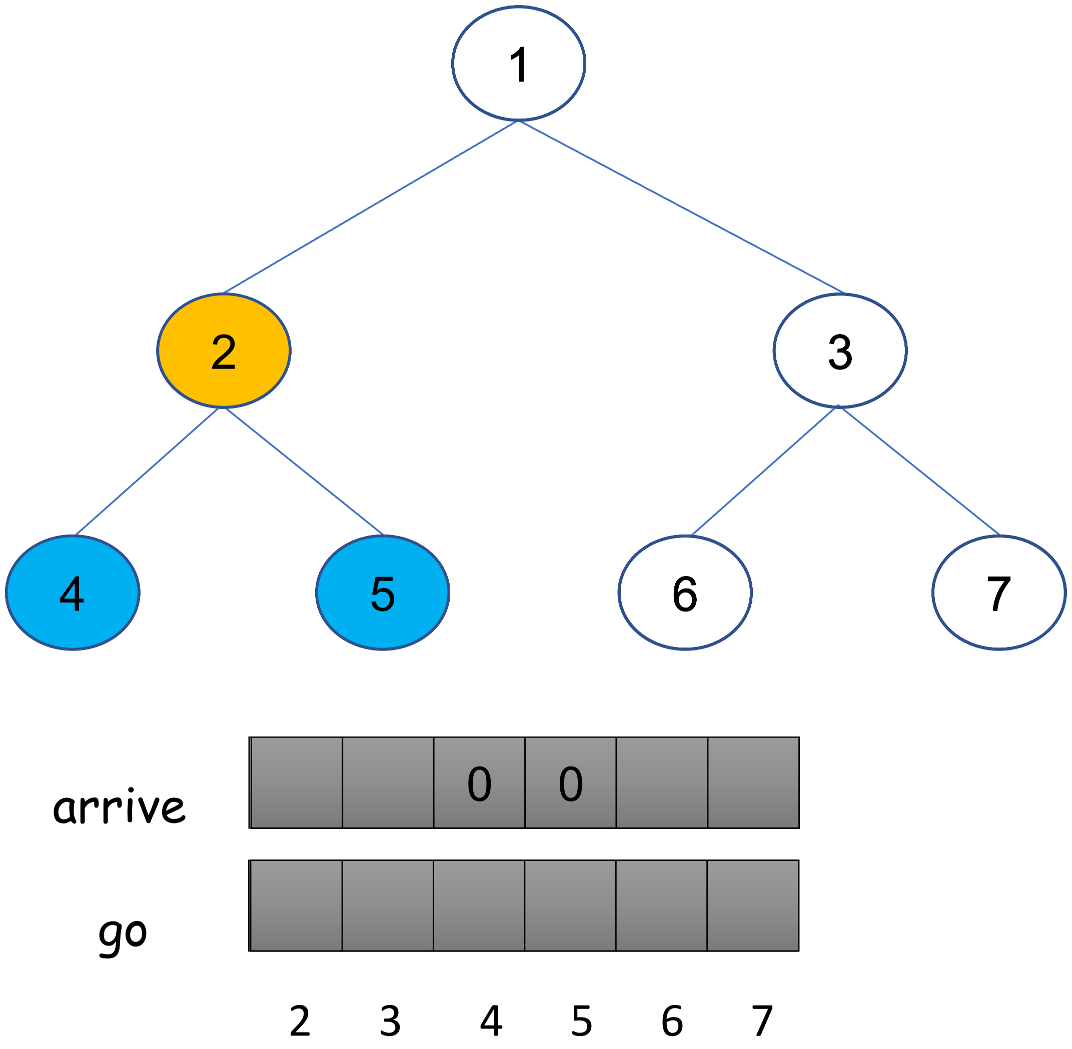
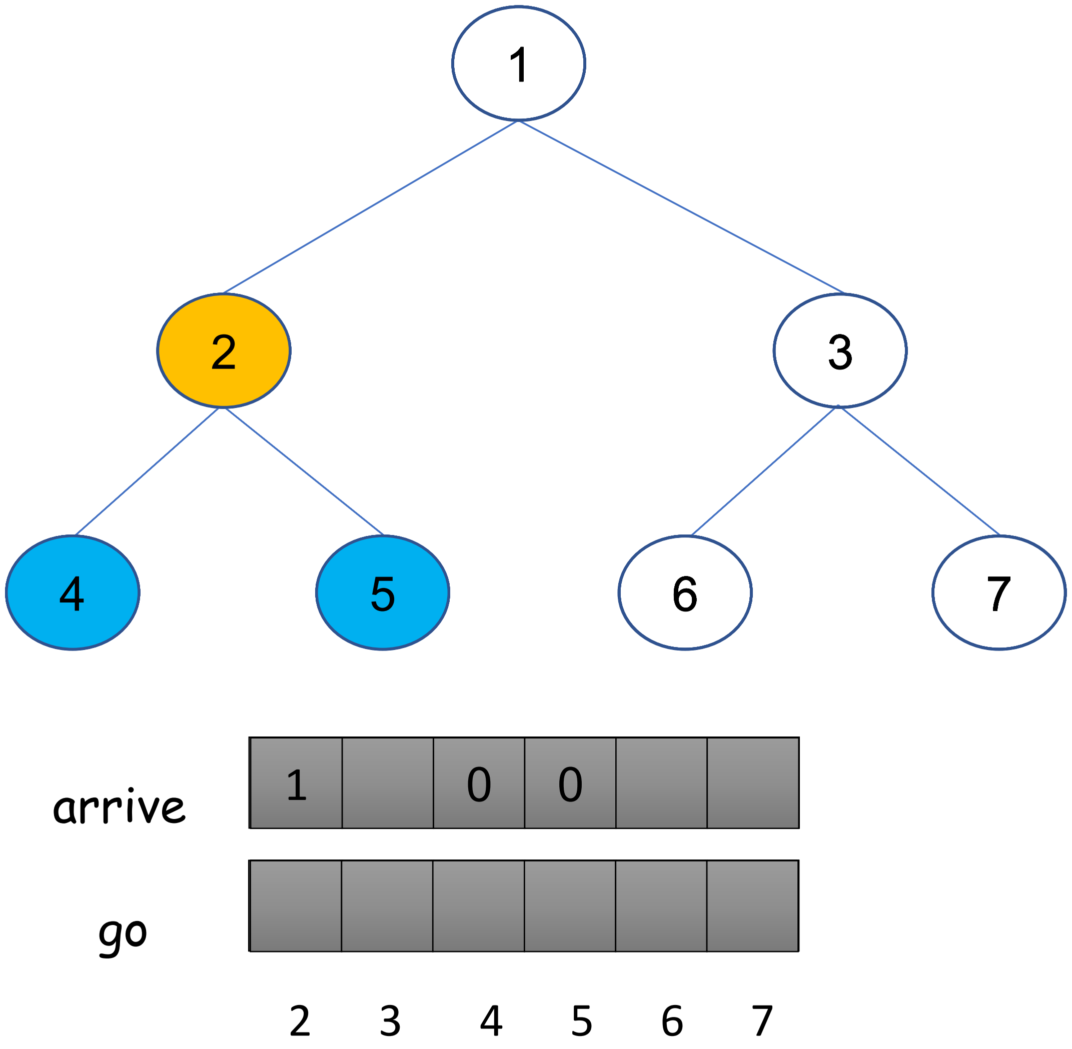


A Tree-based Barrier
Example Run for n=7 threads




```
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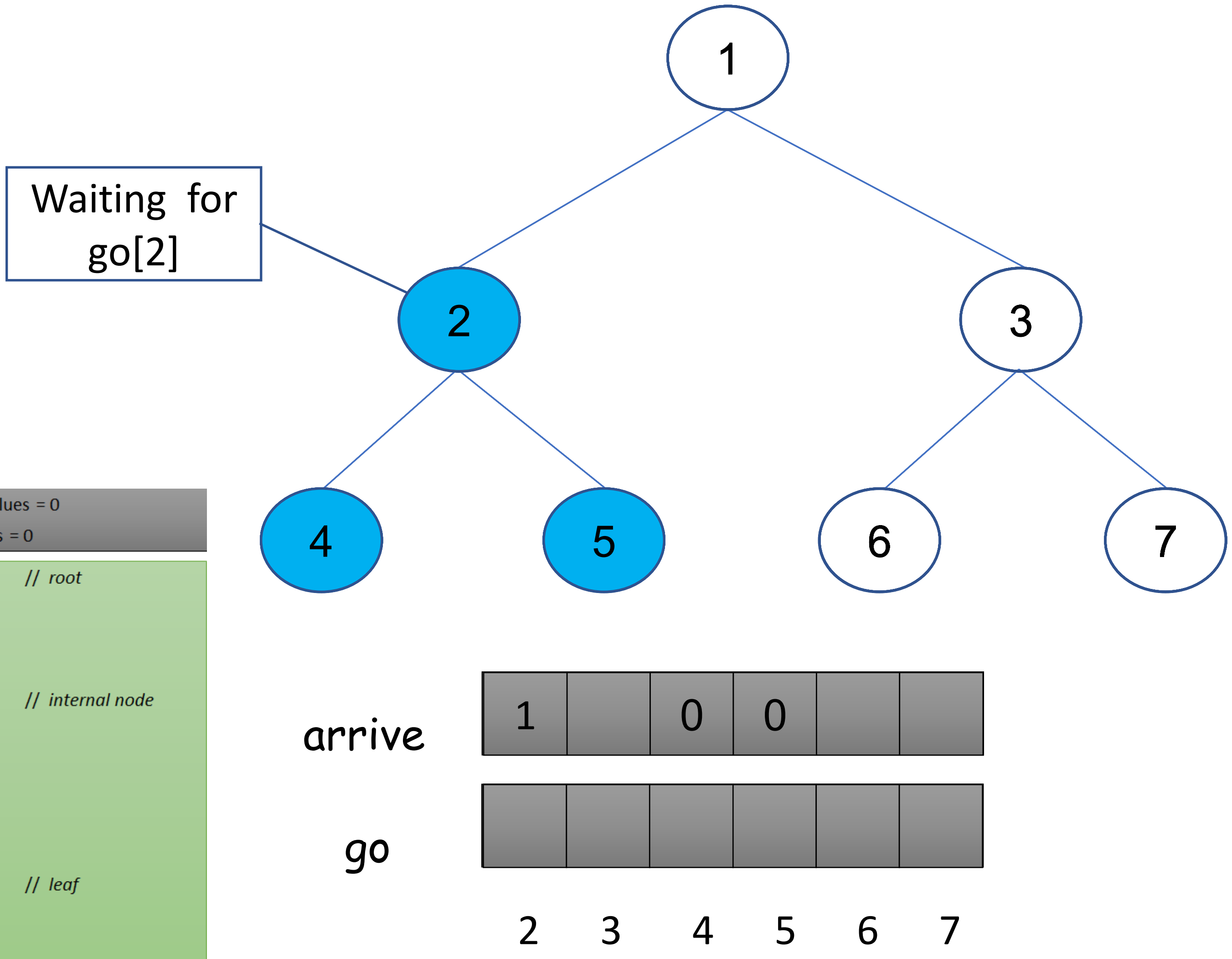
A Tree-based Barrier
Example Run for n=7 threads

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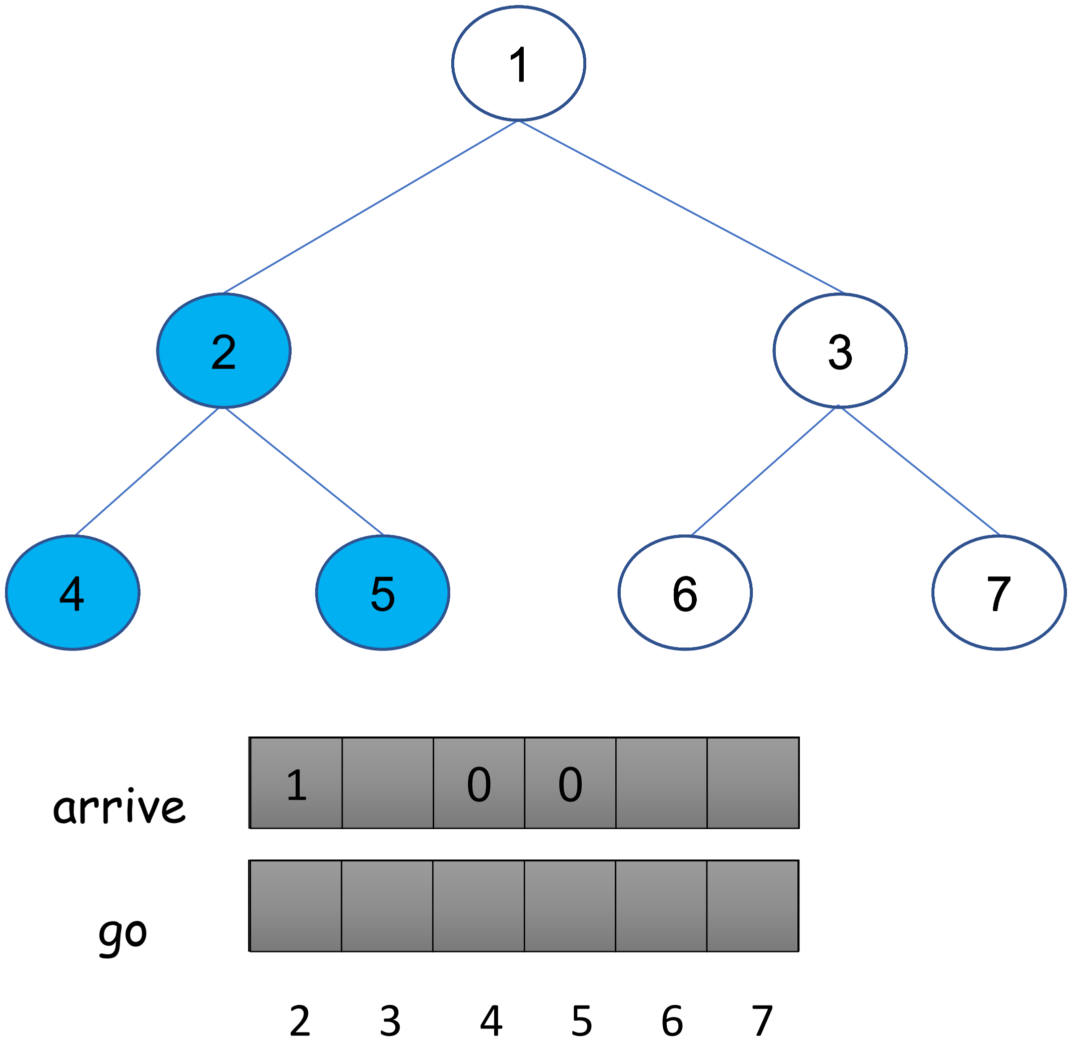
A Tree-based Barrier
Example Run for n=7 threads

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         go[2..n]: array of atomic bits, initial values = 0

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    go[2i] = 1; go[2i+1] := 1
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    arrive[i] := 1
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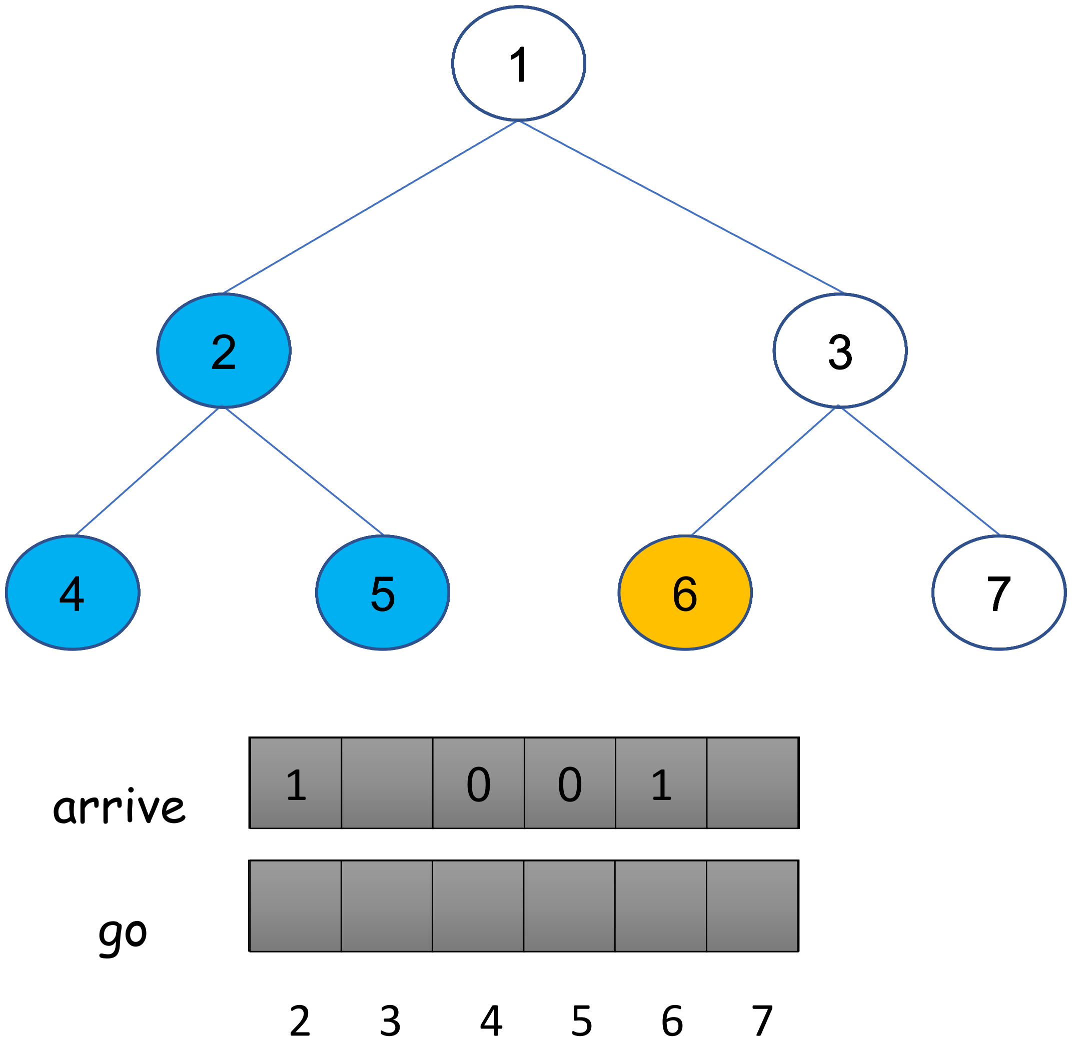
```

A Tree-based Barrier
Example Run for n=7 threads

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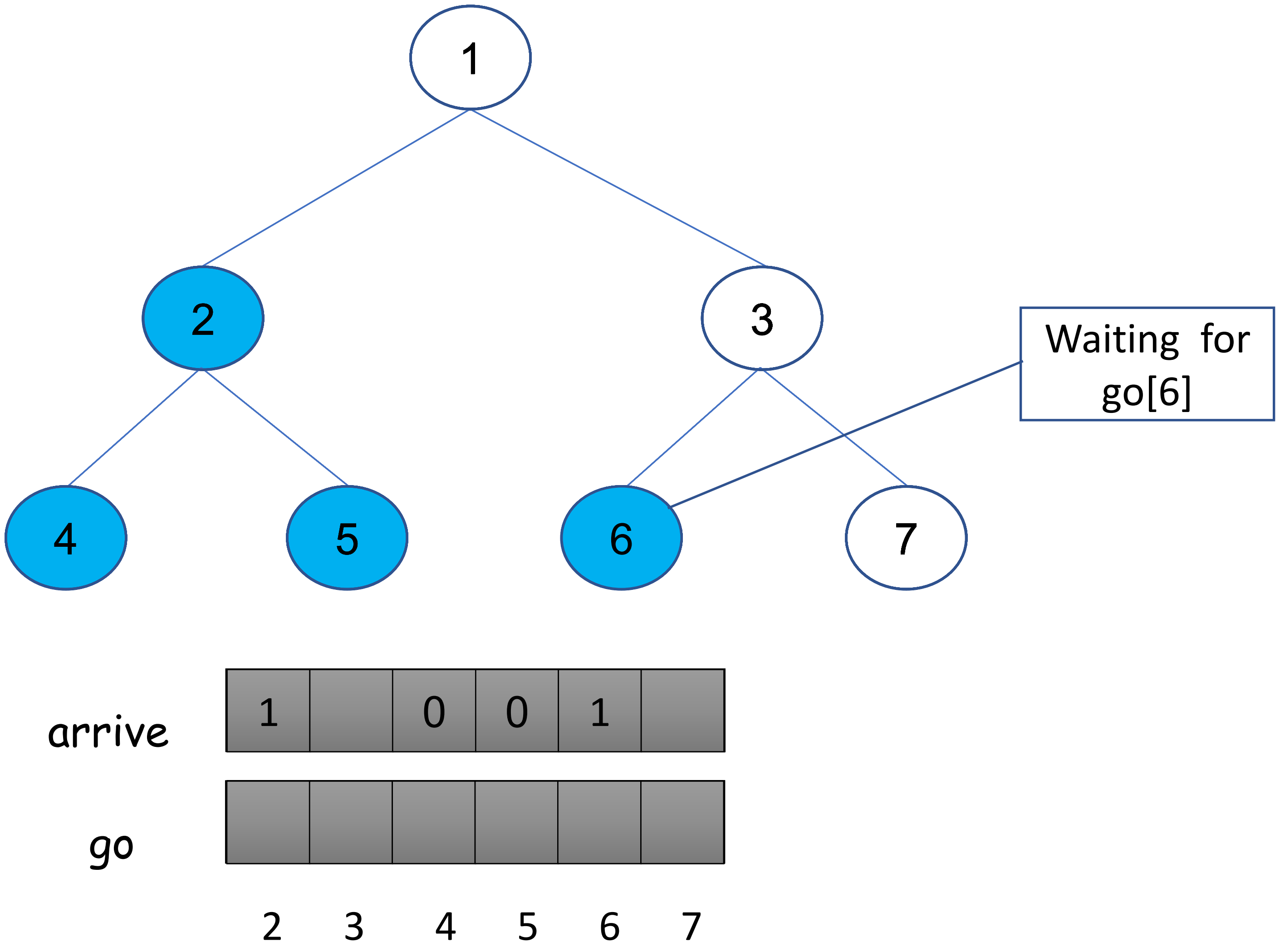
A Tree-based Barrier
Example Run for n=7 threads




```
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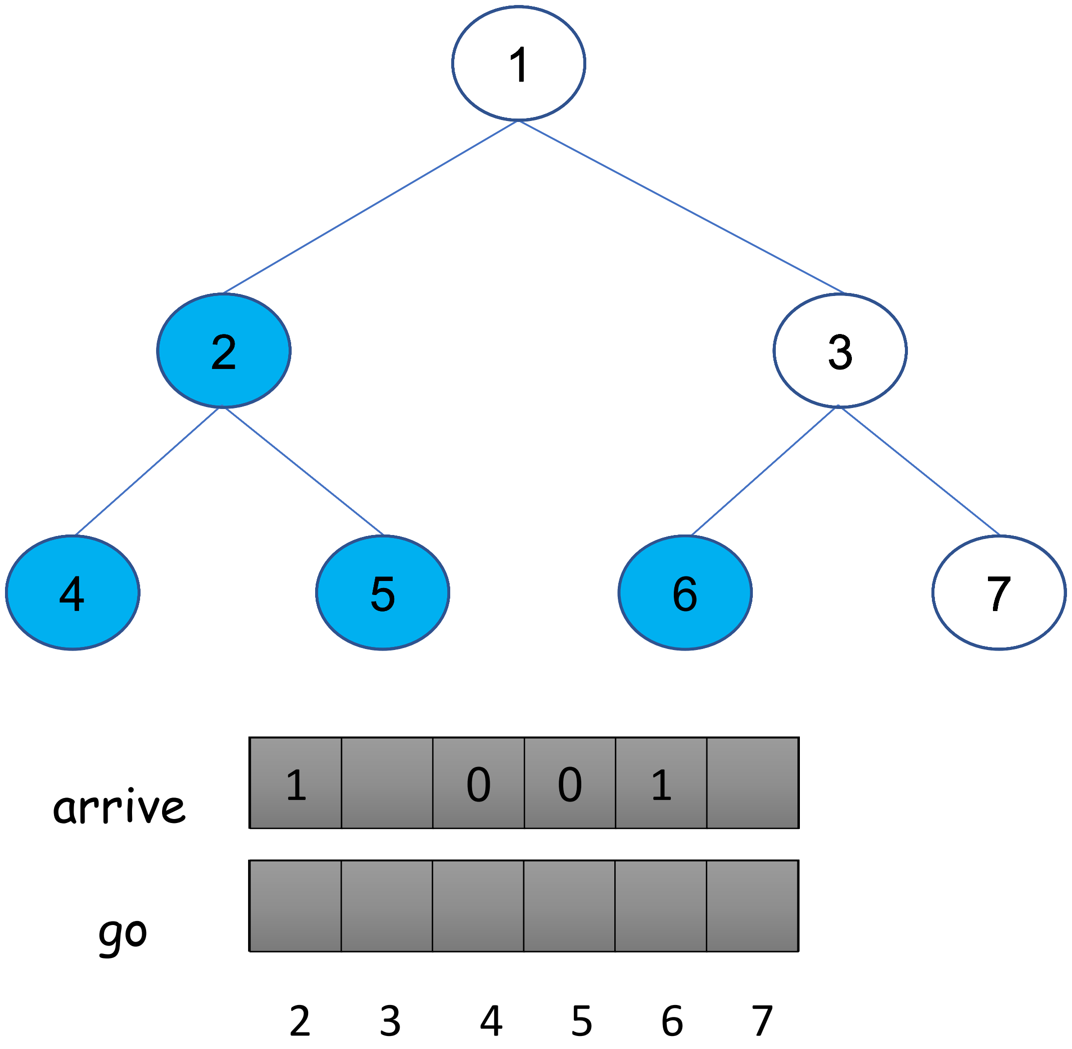
A Tree-based Barrier
Example Run for n=7 threads



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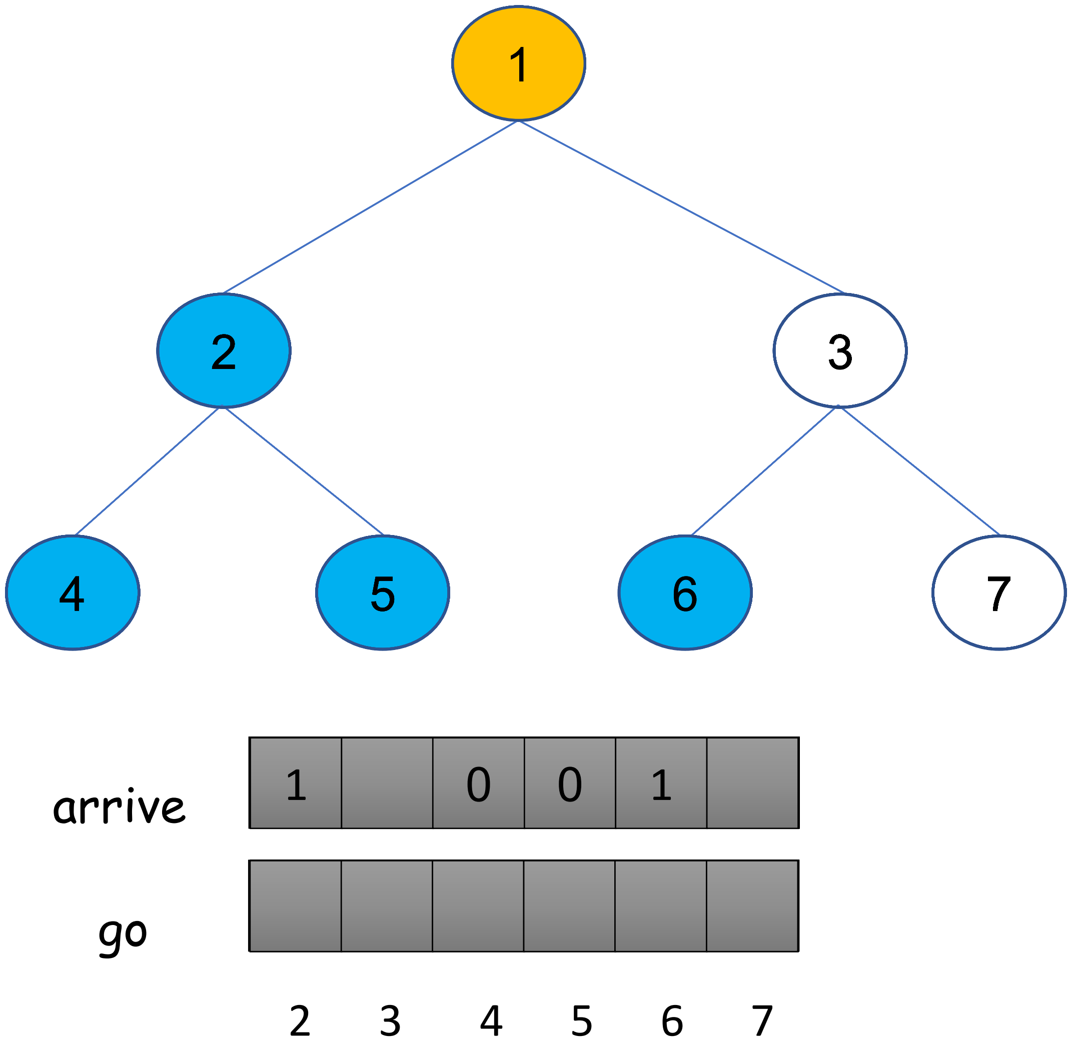
A Tree-based Barrier
Example Run for n=7 threads




```
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      arrive[i] := 1
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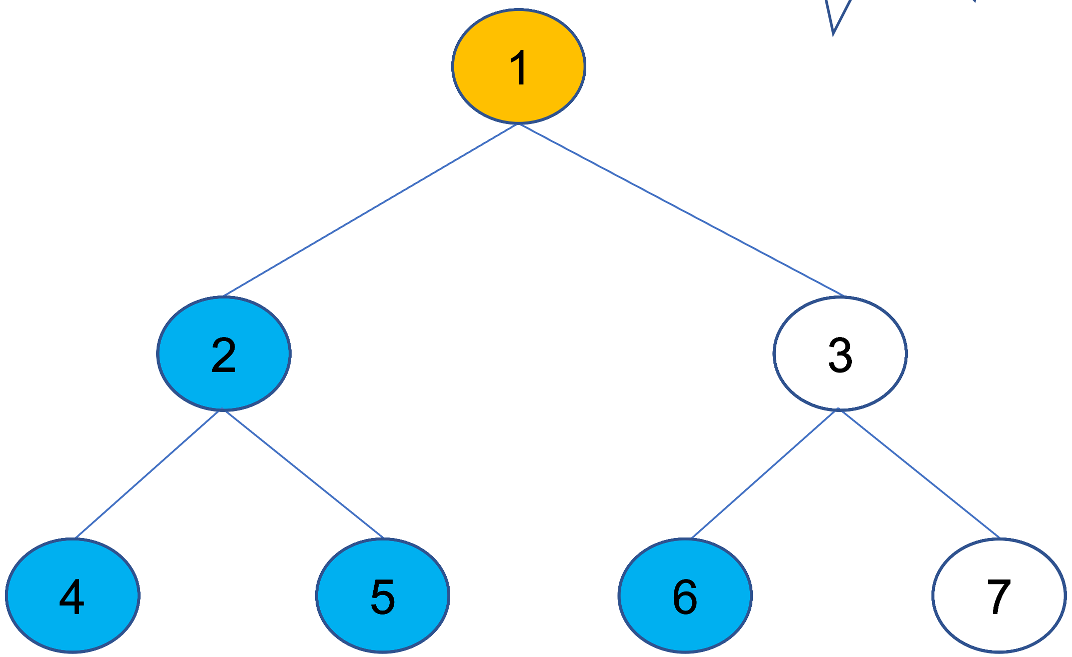
      go[2i] = 1; go[2i+1] := 1
else                                                // leaf
      arrive[i] := 1
      await(go[i] = 1); go[i] := 0 fi
fi
```

A Tree-based Barrier
Example Run for n=7 threads

Arrive[2]=1
?



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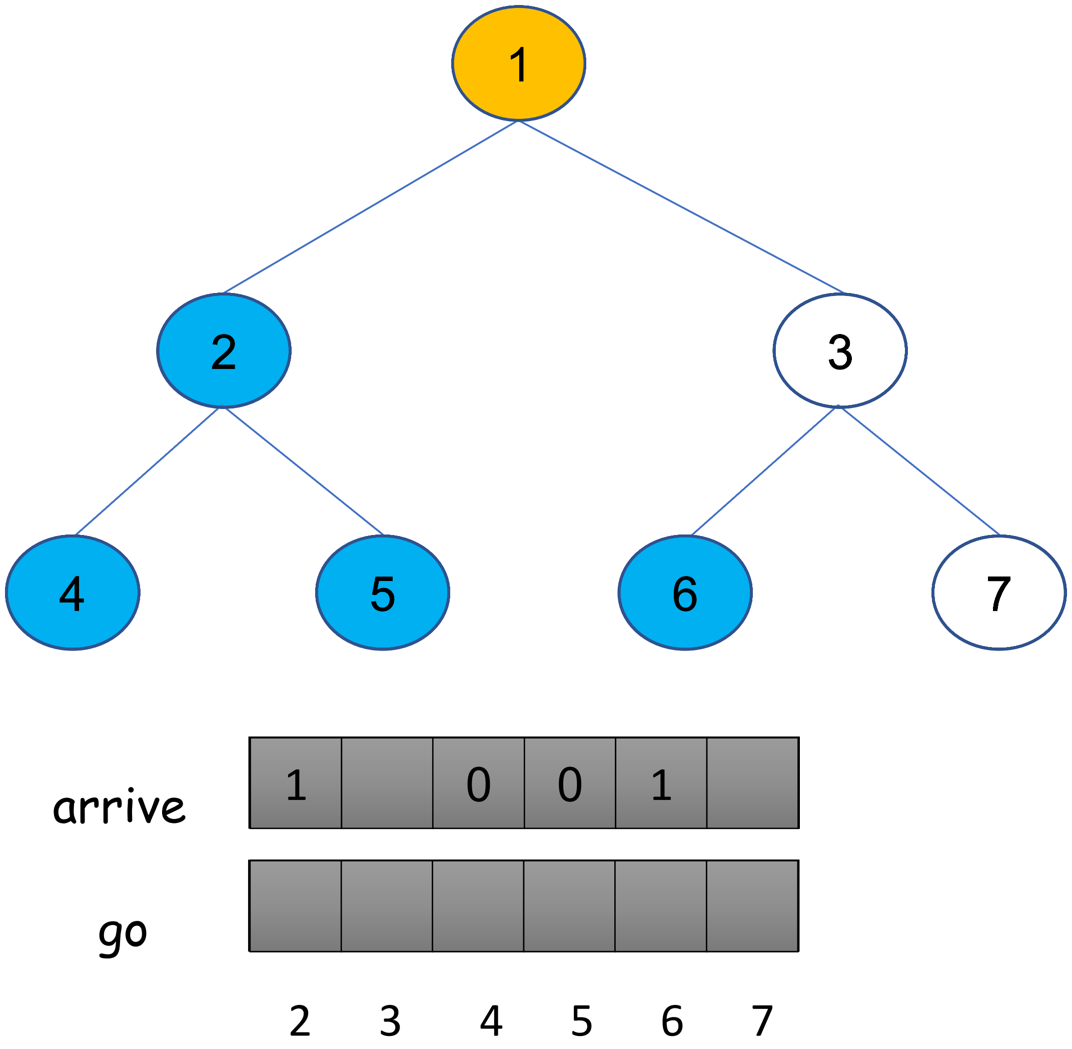
    await(go[i] = 1); go[i] := 0
    go[2i] = 1; go[2i+1] := 1
else                                          // leaf
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0 fi
fi
```

	2	3	4	5	6	7
arrive	1		0	0	1	
go						

A Tree-based Barrier
Example Run for n=7 threads

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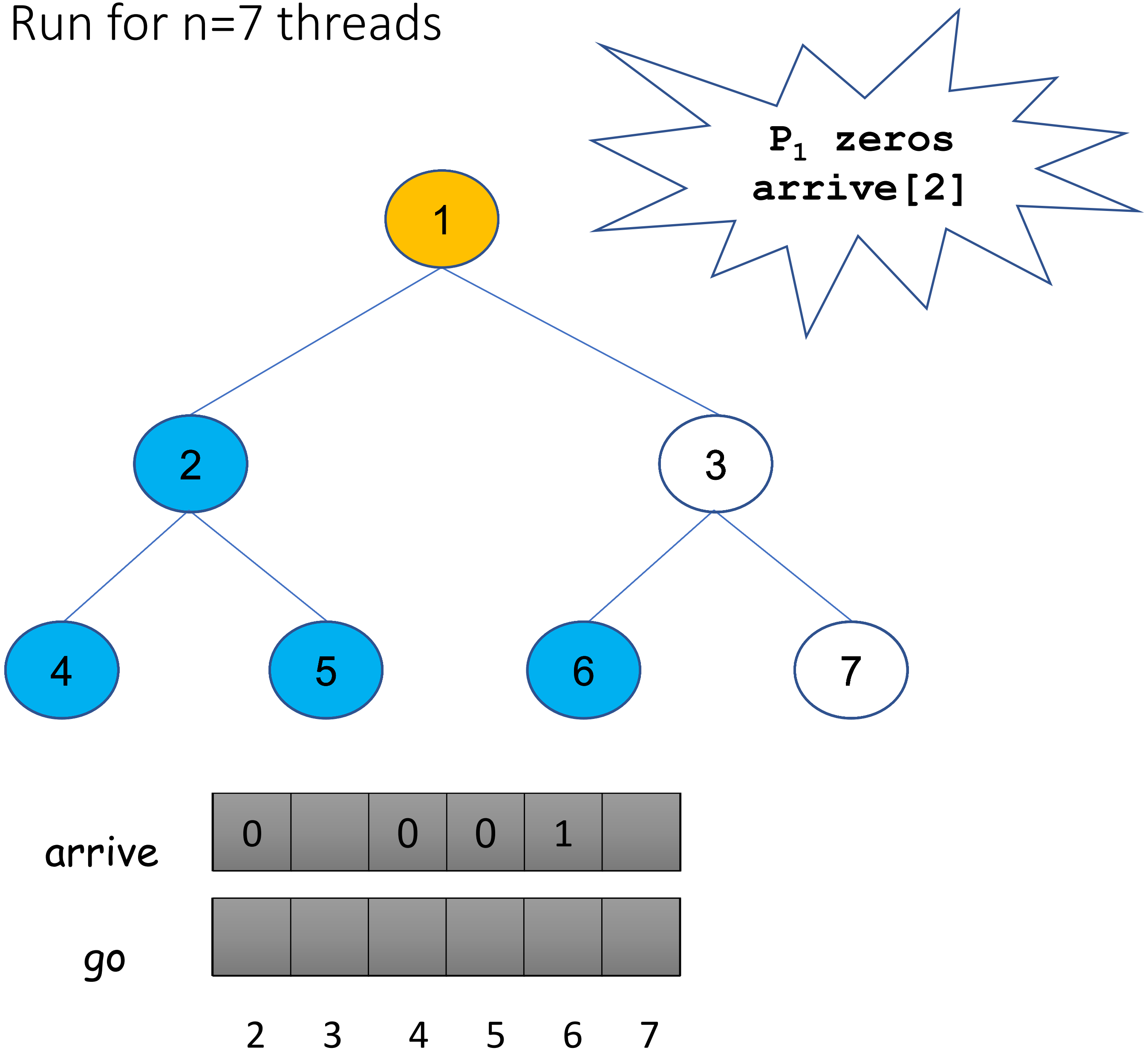
A Tree-based Barrier
Example Run for n=7 threads

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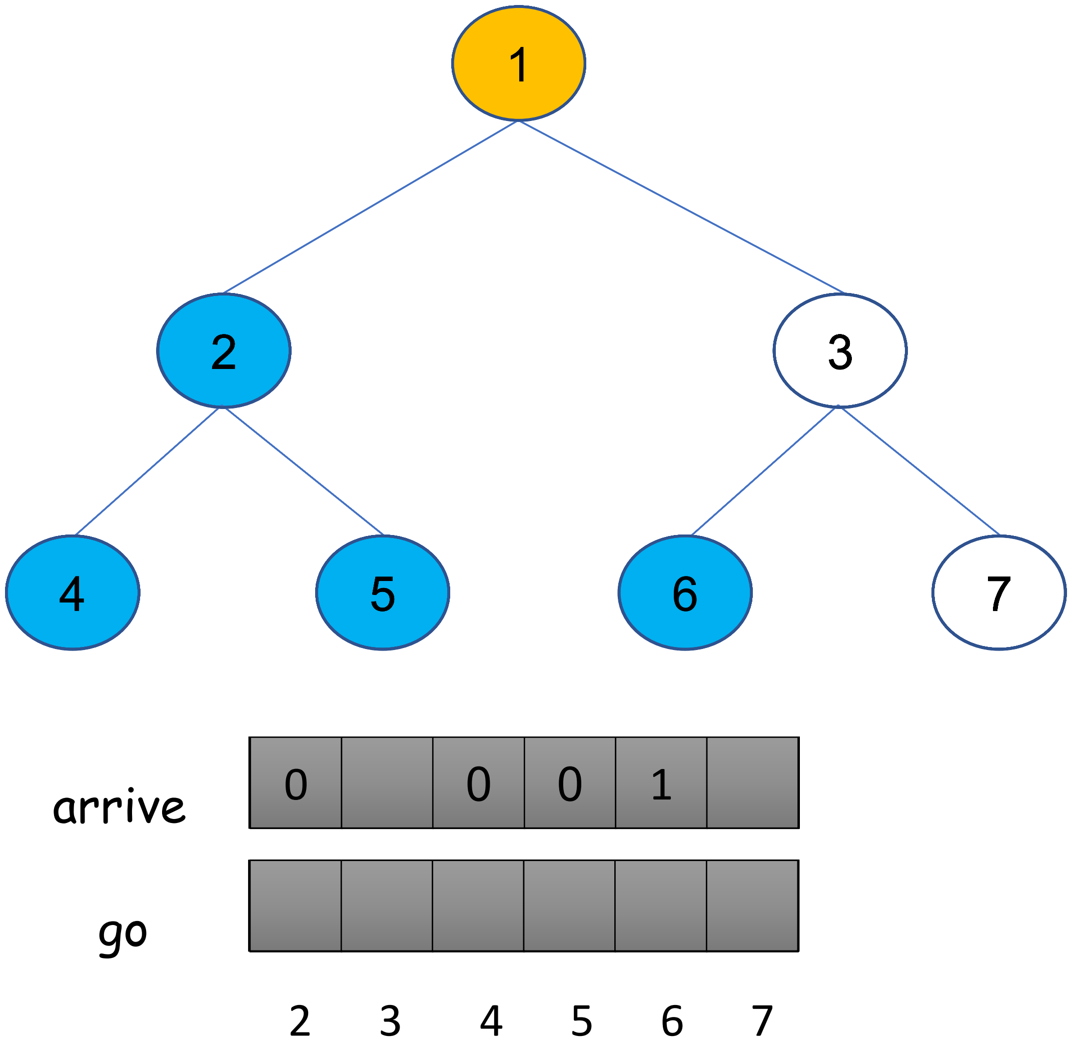
A Tree-based Barrier
Example Run for n=7 threads



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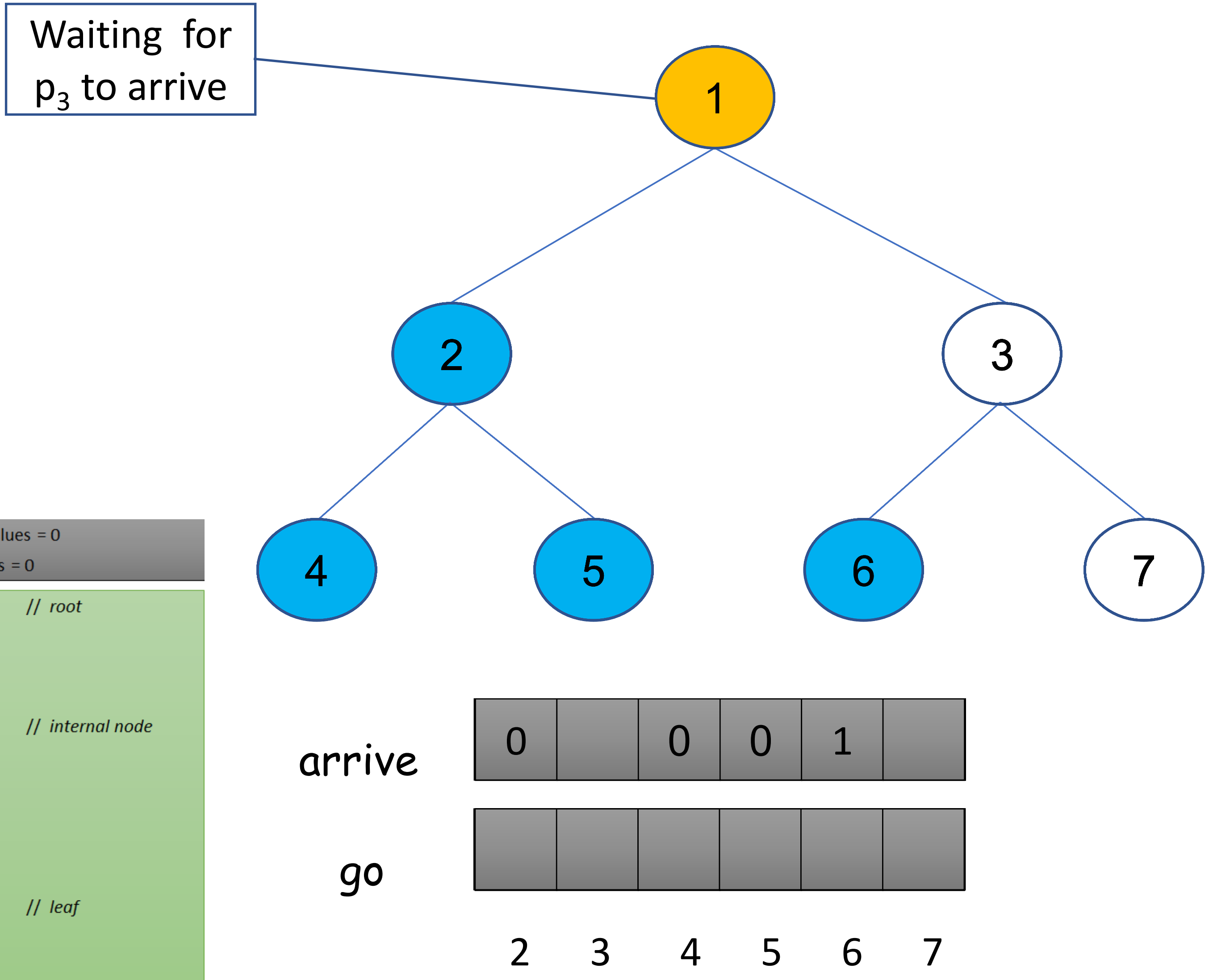
A Tree-based Barrier
Example Run for n=7 threads

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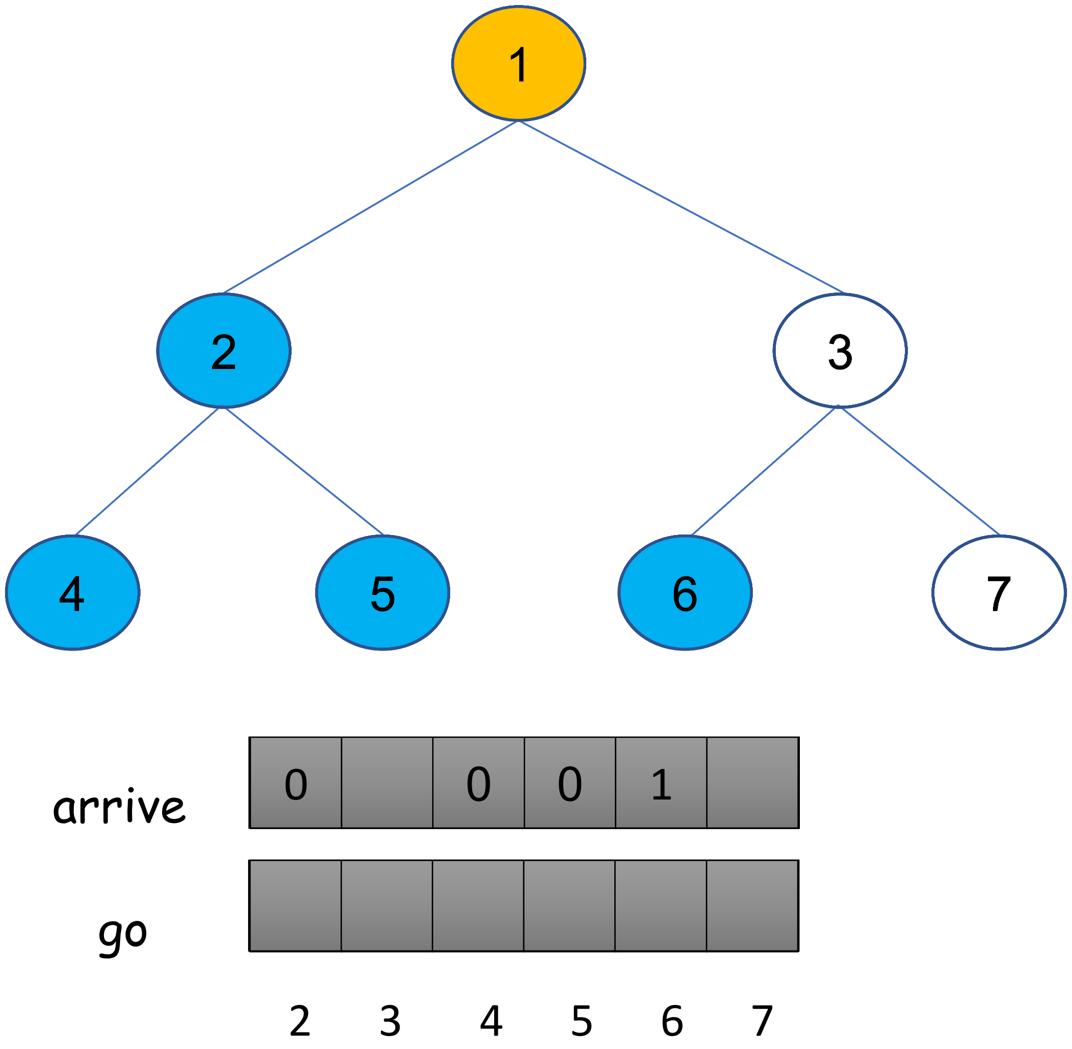
A Tree-based Barrier
Example Run for n=7 threads

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A Tree-based Barrier
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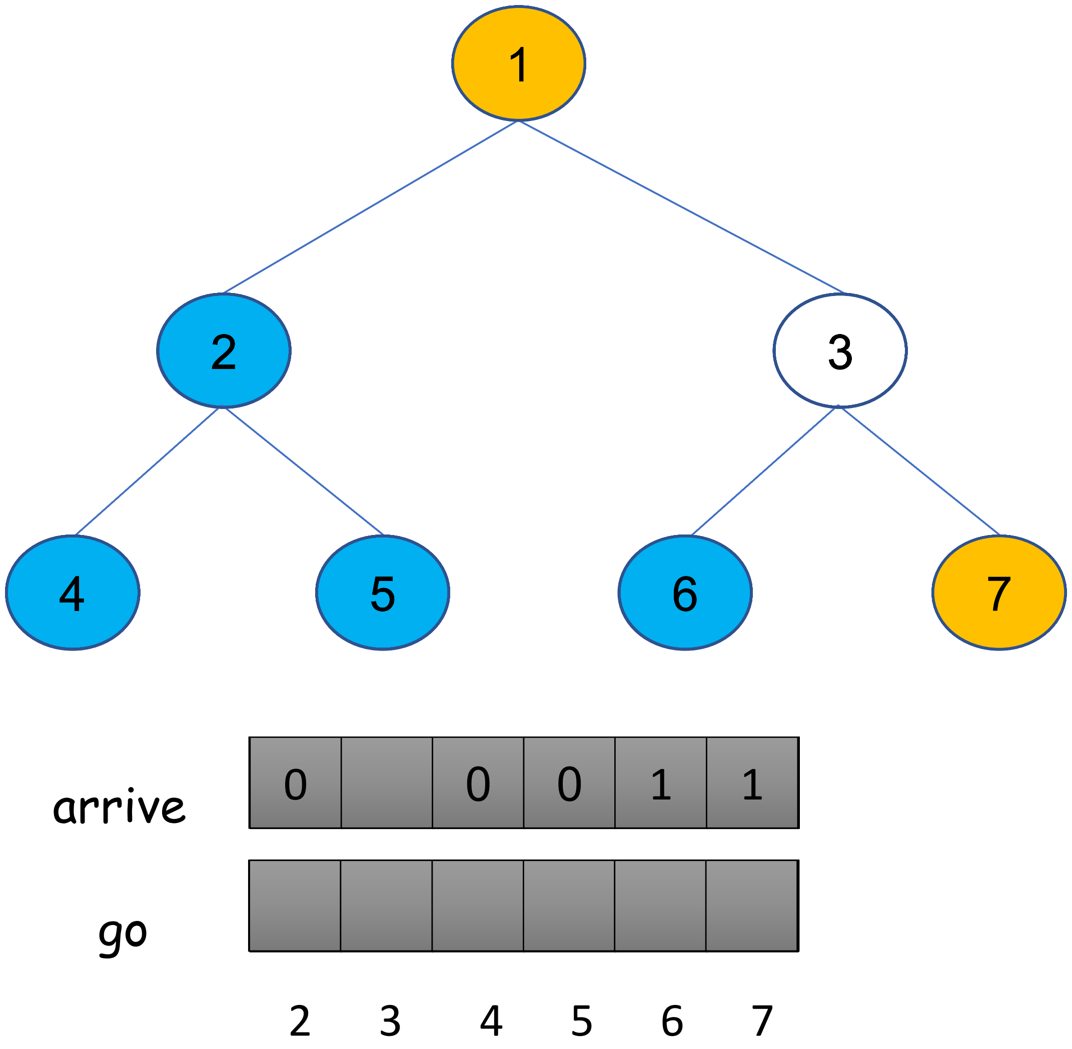

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A Tree-based Barrier
Example Run for n=7 threads

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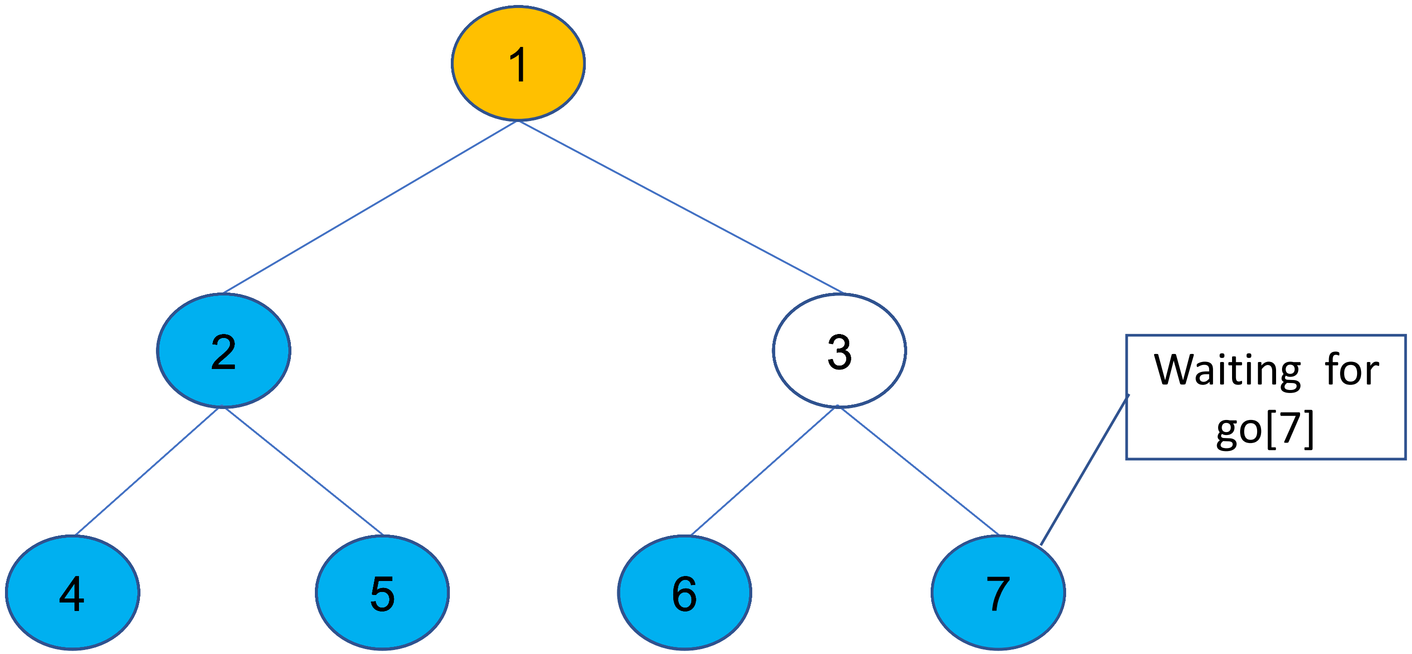
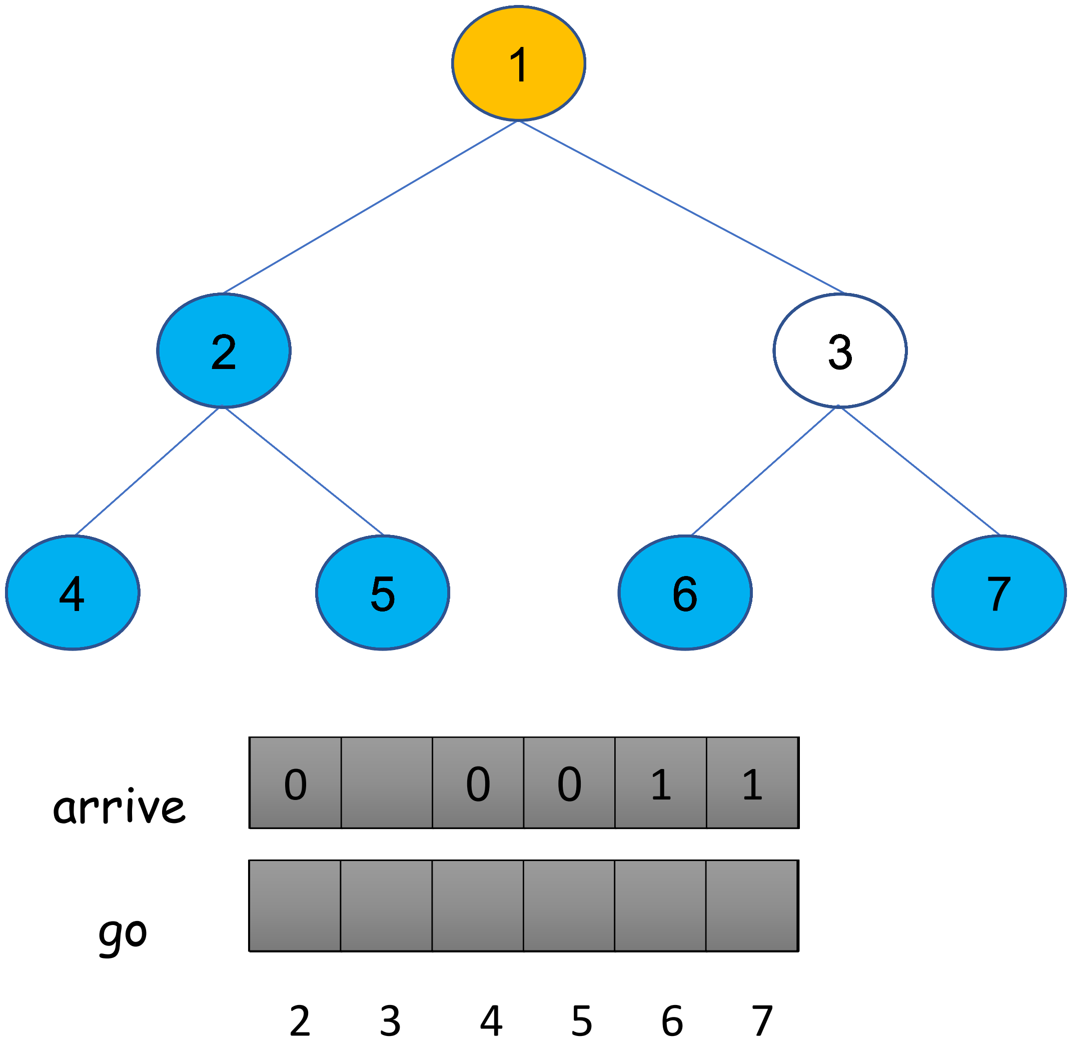
fi
```



	2	3	4	5	6	7
arrive	0		0	0	1	1
go						

A Tree-based Barrier
Example Run for n=7 threads



shared	arrive[2..n]: array of atomic bits, initial values = 0
	go[2..n]: array of atomic bits, initial values = 0

```
if i=1 then                                        // root
        await(arrive[2] = 1); arrive[2] := 0
        await(arrive[3] = 1); arrive[3] := 0
        go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                           // internal node
        await(arrive[2i] = 1); arrive[2i] := 0
        await(arrive[2i+1] = 1); arrive[2i+1] := 0
        arrive[i] := 1
        await(go[i] = 1); go[i] := 0
        go[2i] = 1; go[2i+1] := 1
else                                               // leaf
        arrive[i] := 1
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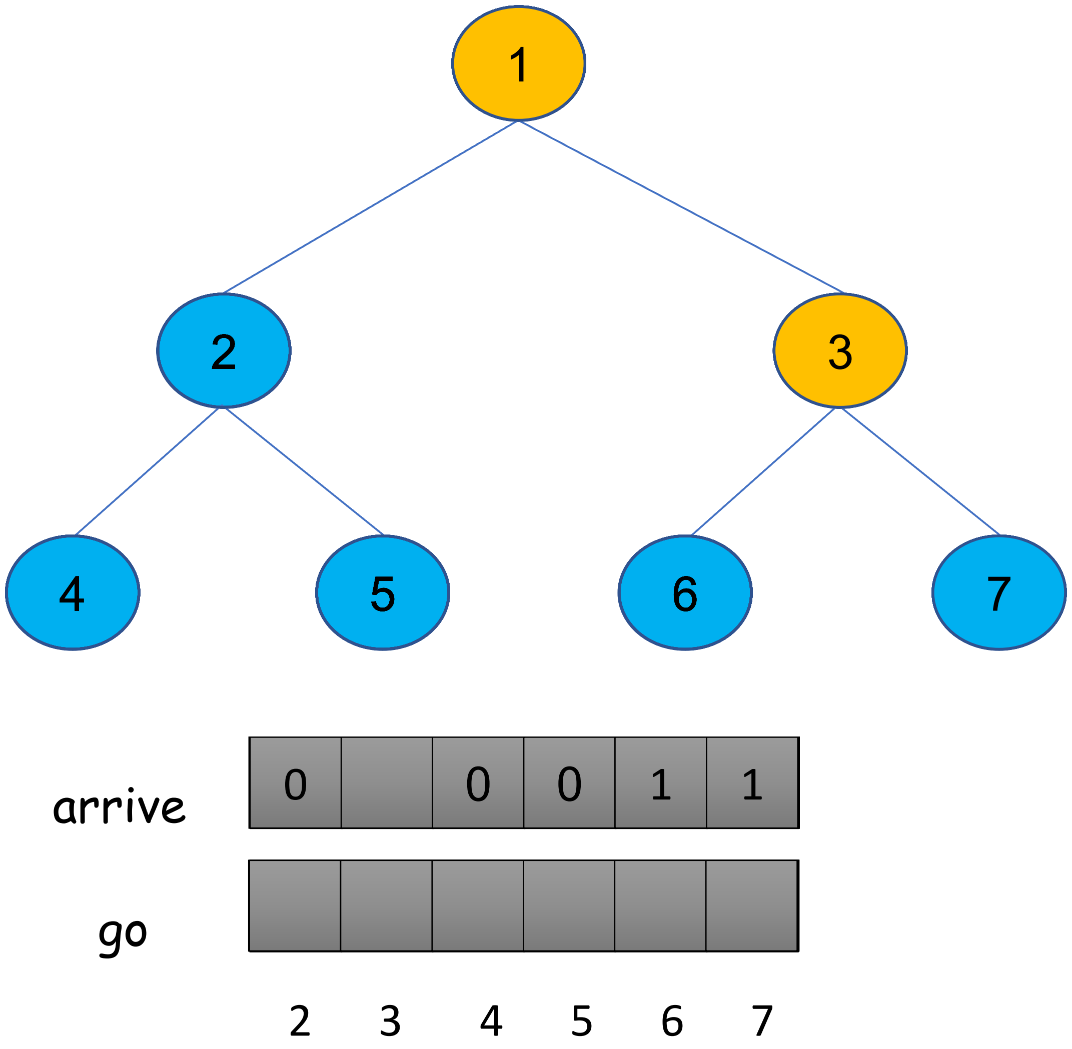
fi
```

A Tree-based Barrier
Example Run for n=7 threads

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    arrive[i] := 1
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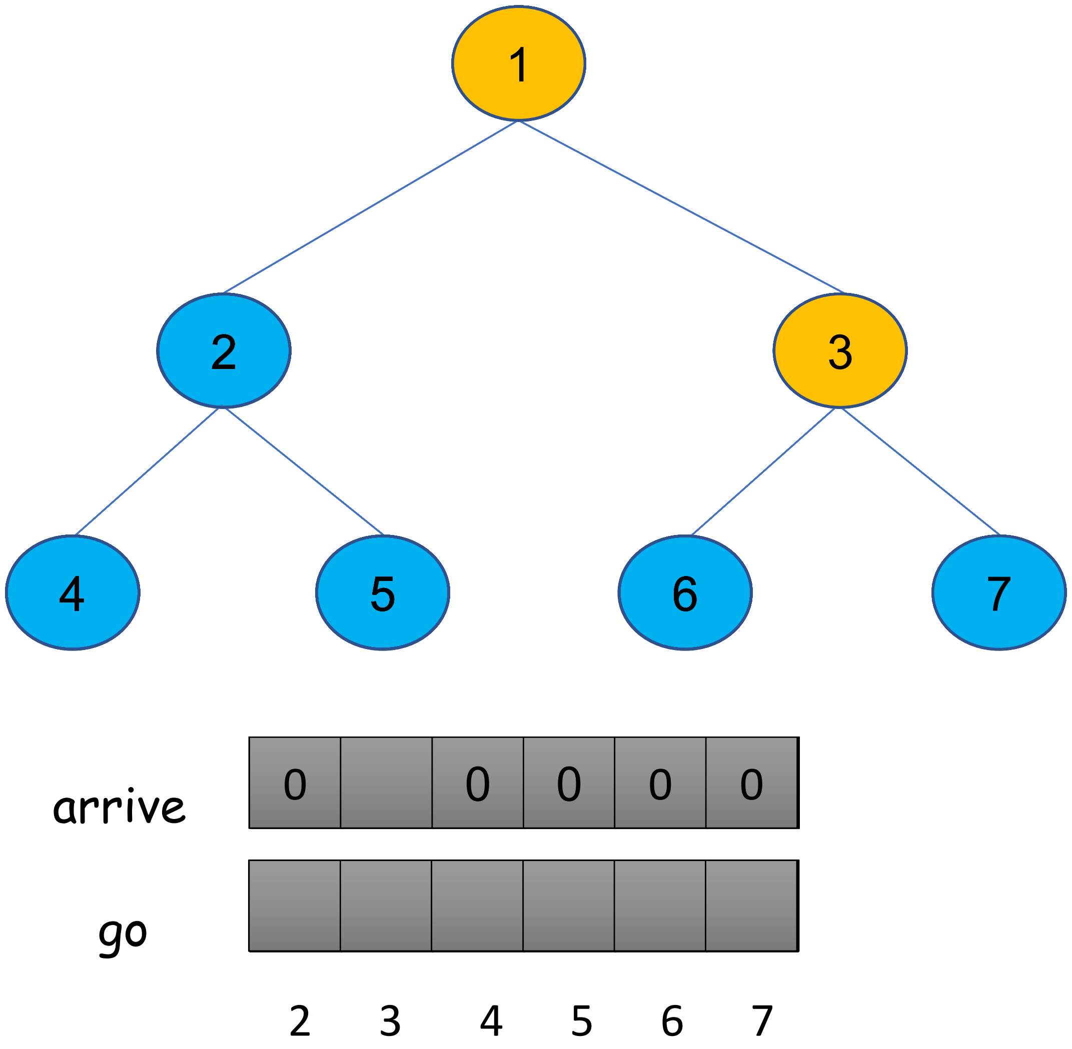
fi
```

A Tree-based Barrier
Example Run for n=7 threads

P_3 zeros arrive[6,7]




```
shared  arrive[2..n]: array of atomic bits, initial values = 0
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if i=1 then                                   // root
    await(arrive[2] = 1); arrive[2] := 0
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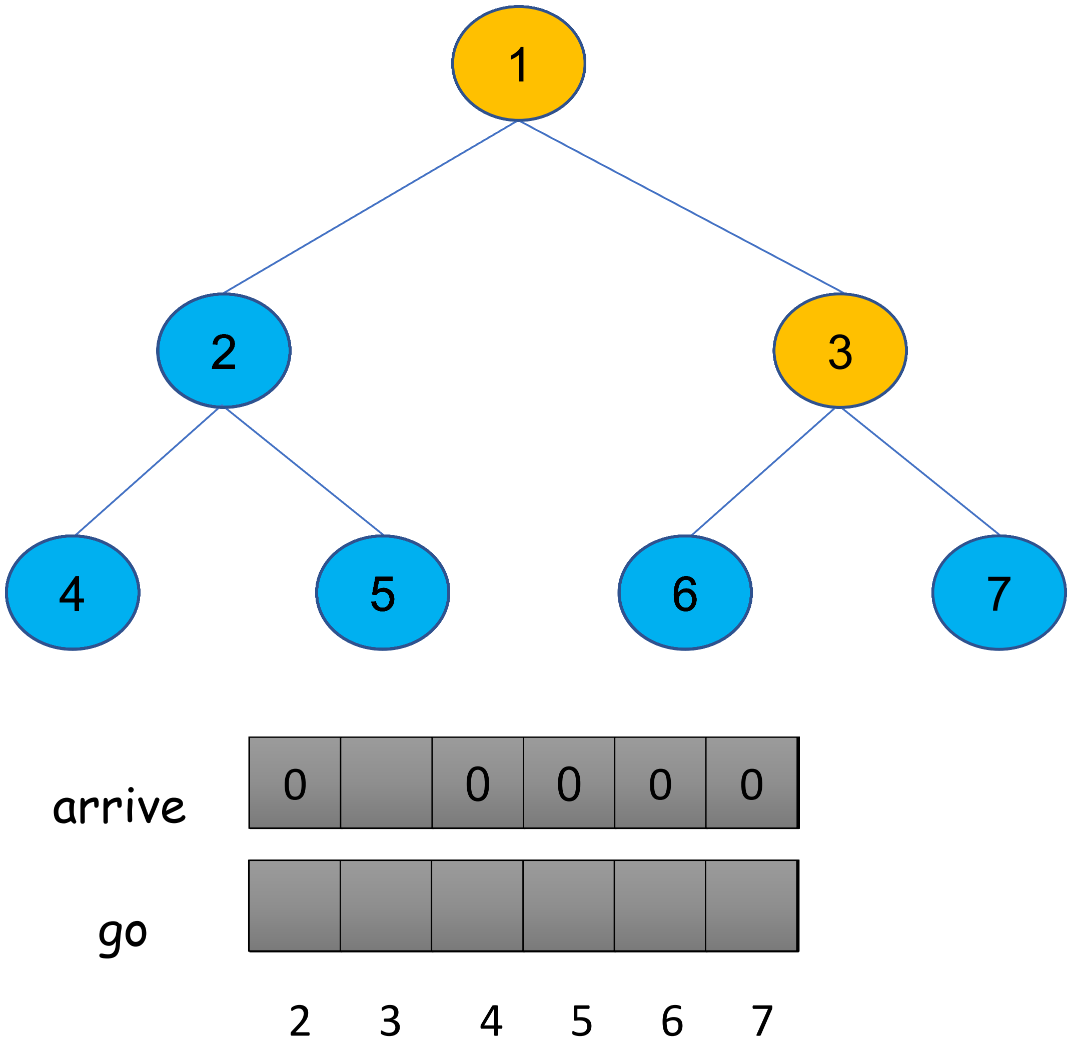
else                                          // leaf
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0 fi
fi
```

A Tree-based Barrier
Example Run for n=7 threads

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         go[2..n]: array of atomic bits, initial values = 0

if i=1 then                                          // root
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else                                                 // leaf
        arrive[i] := 1
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A Tree-based Barrier
Example Run for n=7 threads

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shared    arrive[2..n]:  array of atomic bits, initial values = 0
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      arrive[i]  := 1
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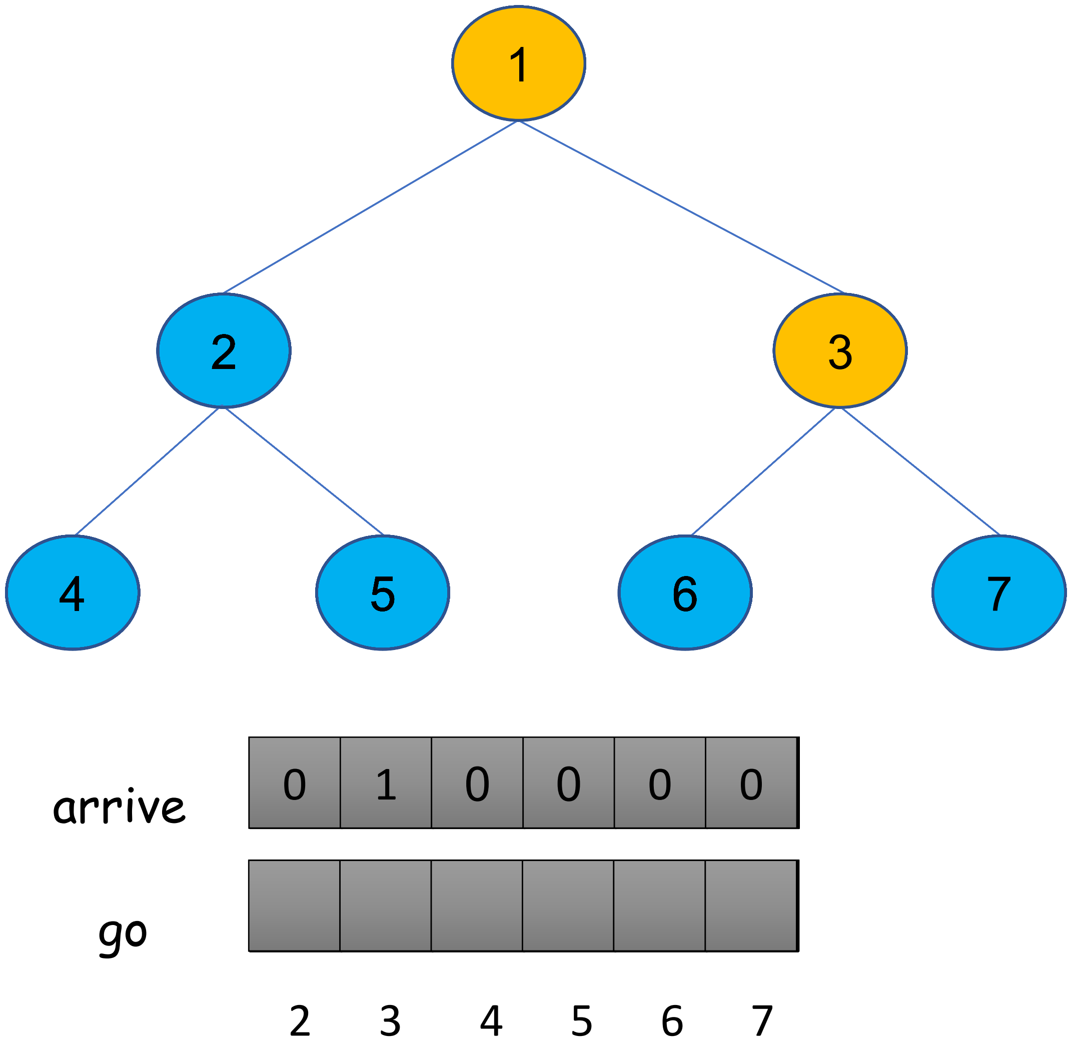
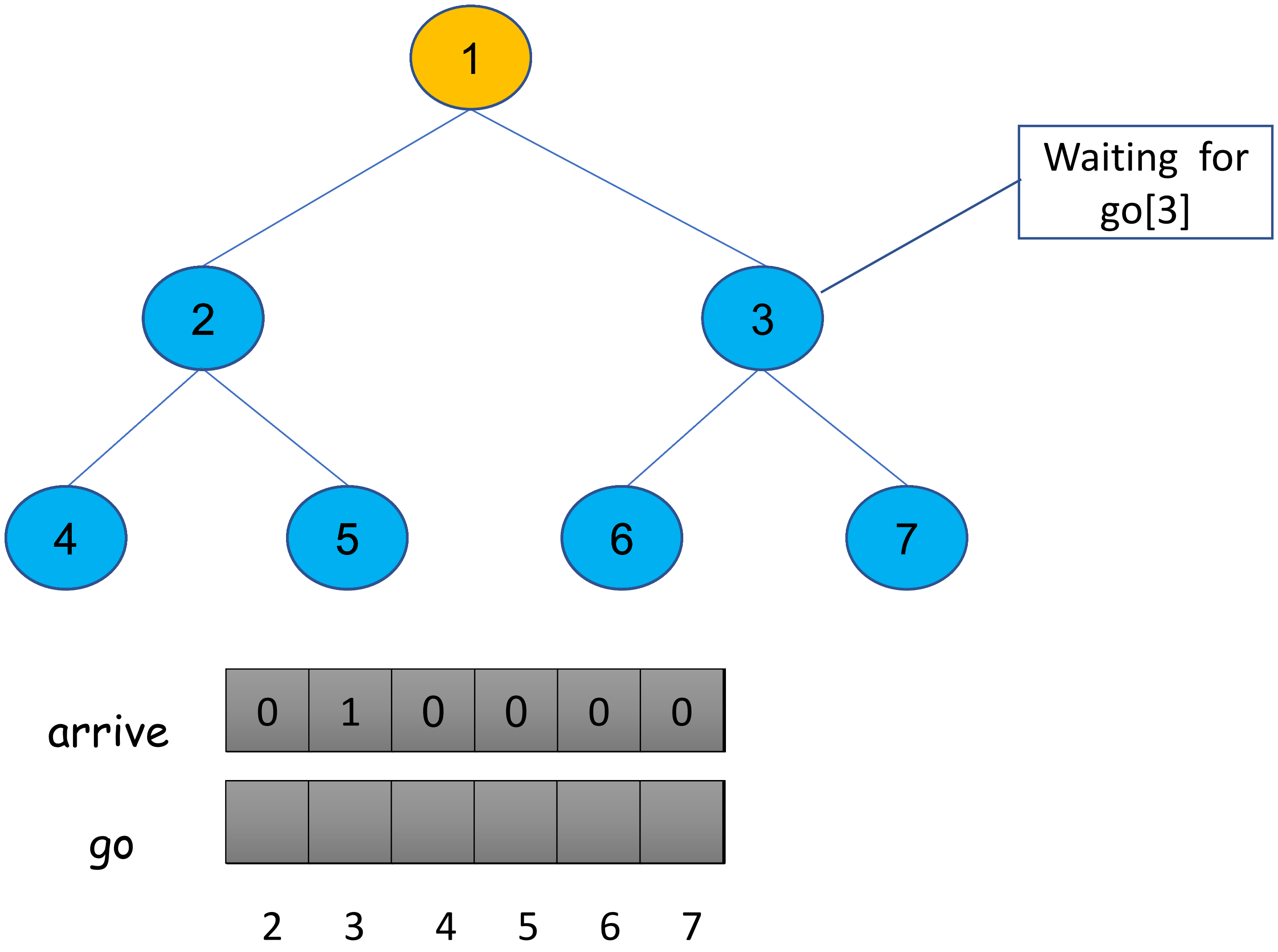


A Tree-based Barrier
Example Run for n=7 threads

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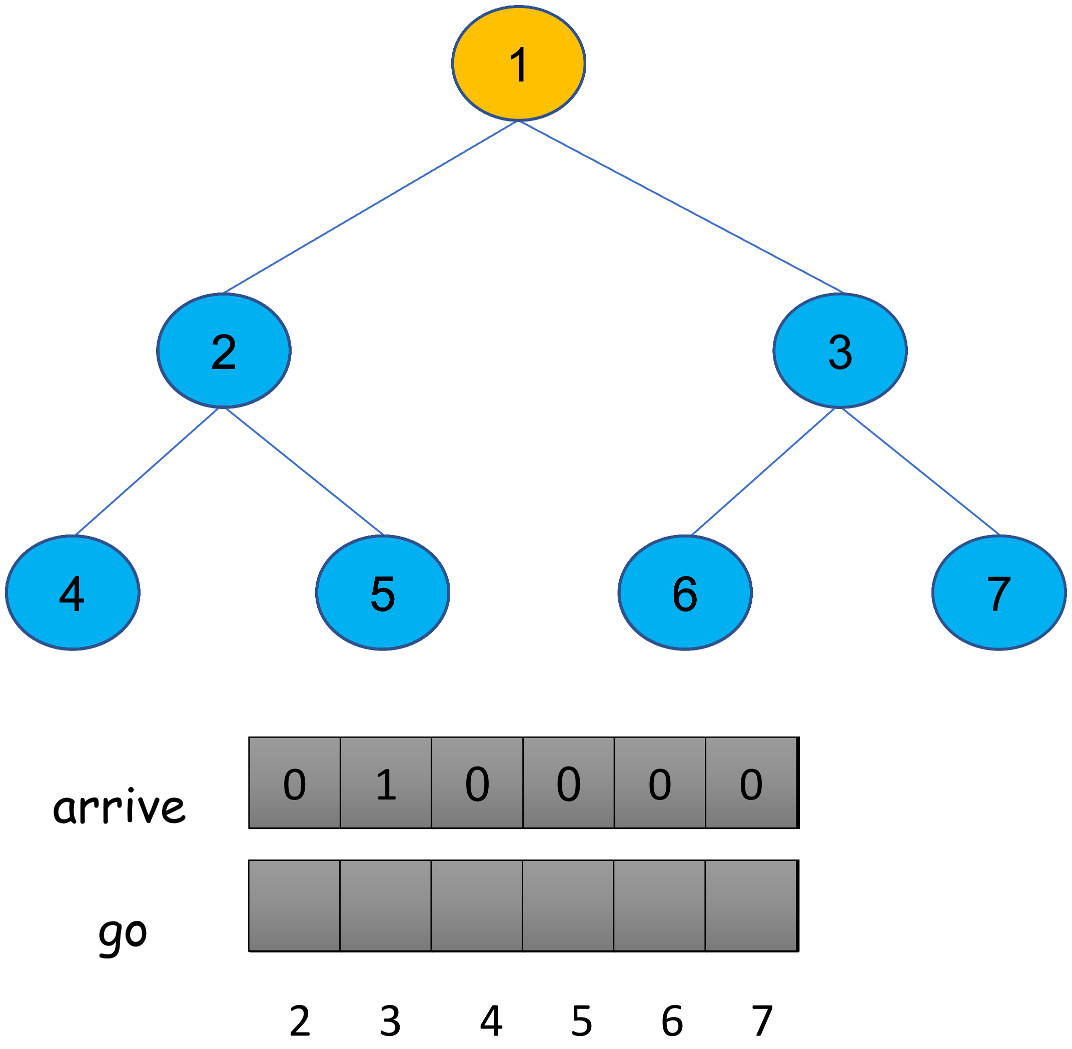
A Tree-based Barrier
Example Run for n=7 threads

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```

```
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      arrive[i] := 1
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      go[2i] = 1; go[2i+1] := 1
else                                             // leaf
      arrive[i] := 1
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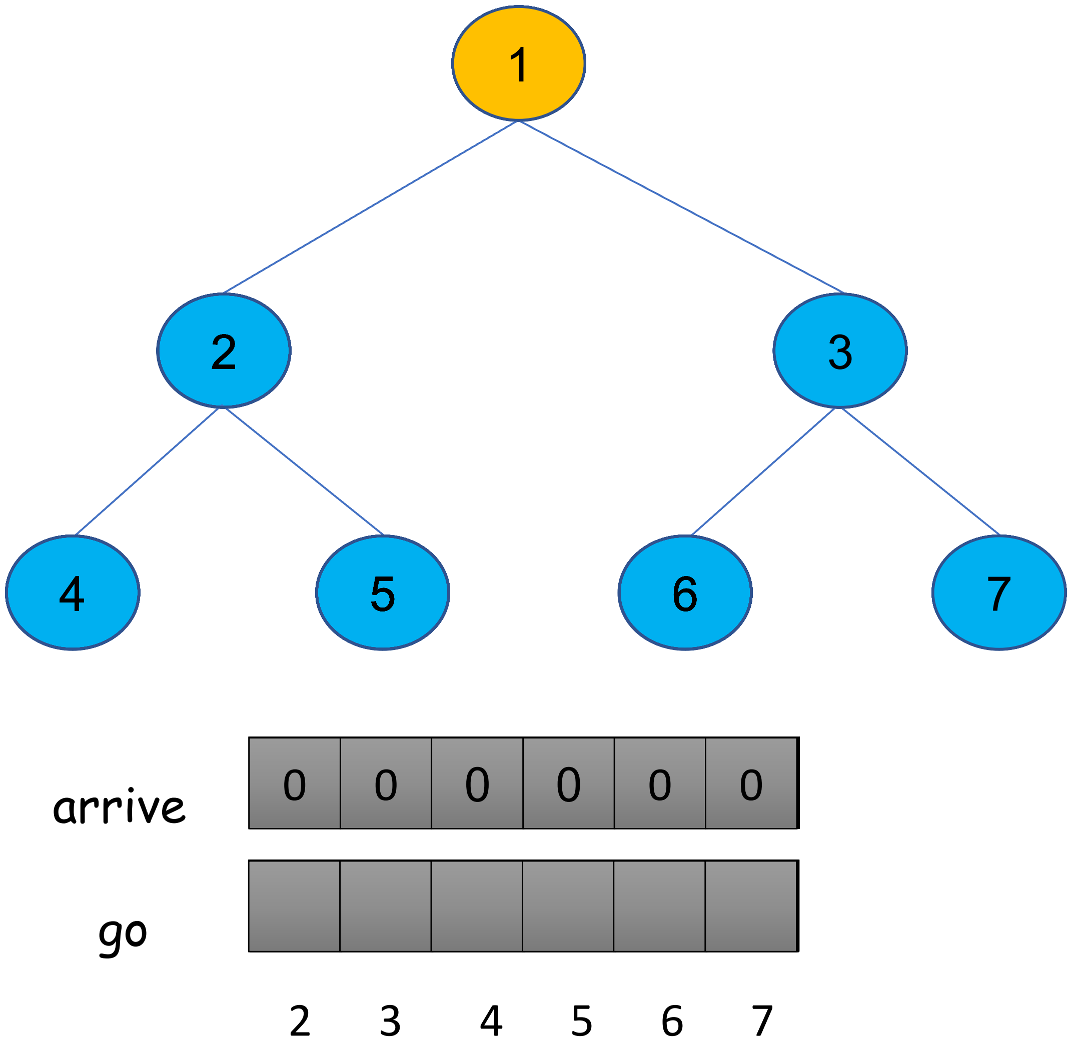
fi
```

A Tree-based Barrier
Example Run for n=7 threads

P_1 zeros arrive[3]




```
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```

```
if i=1 then                                   // root
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      go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                      // internal node
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      arrive[i] := 1
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else                                          // leaf
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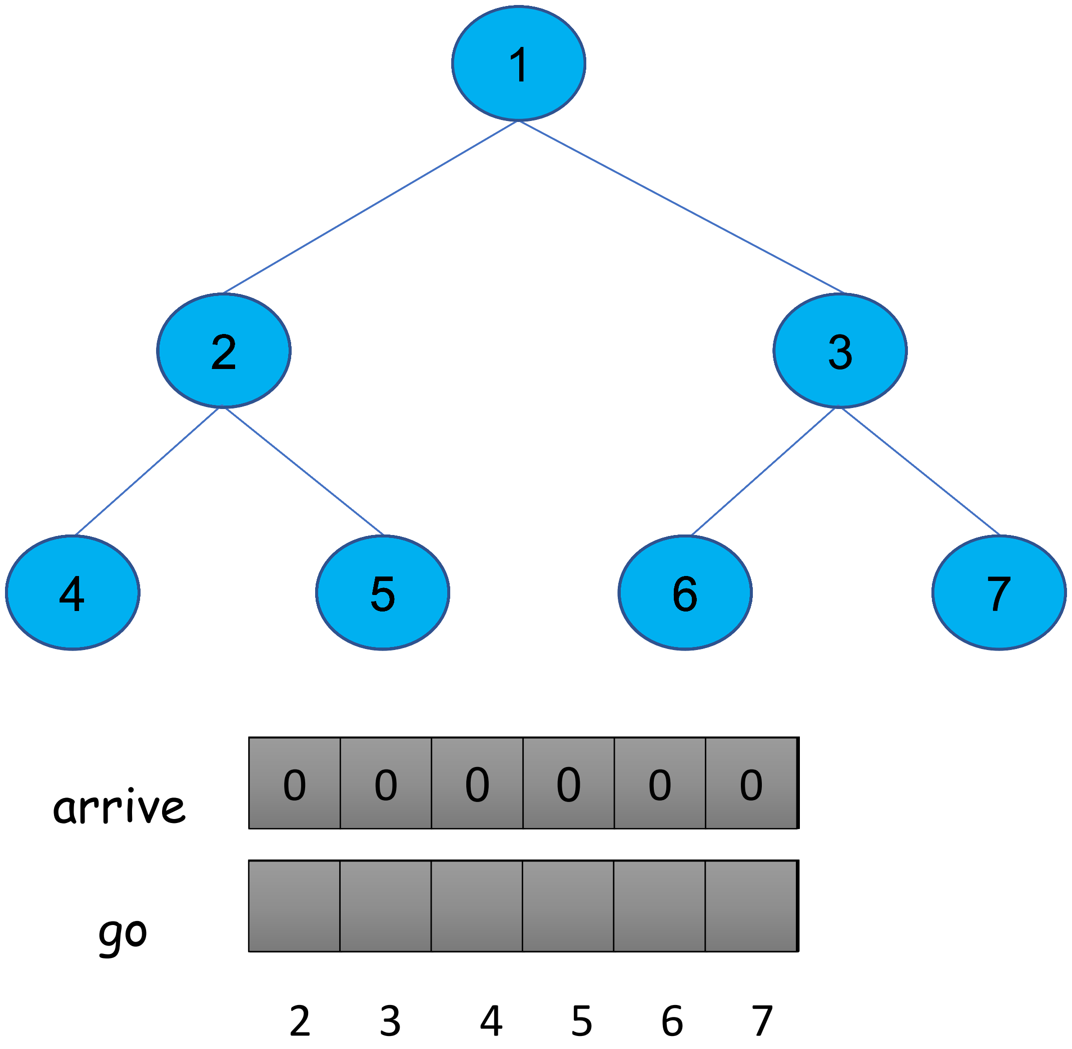
```

A Tree-based Barrier
Example Run for n=7 threads

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    go[2] = 1; go[3] = 1
else if i ≤ (n-1)/2 then                             // internal node
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A Tree-based Barrier
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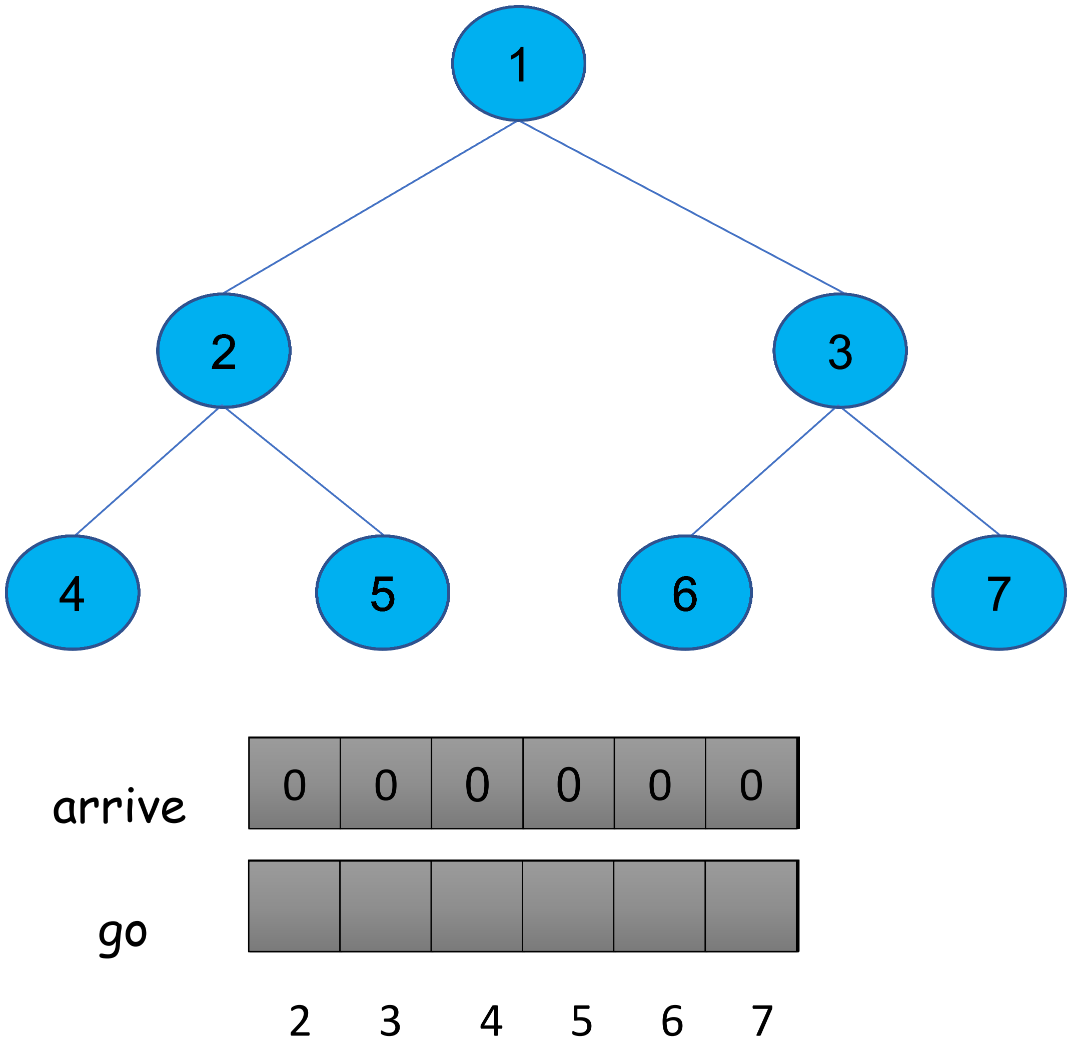


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else if i ≤ (n-1)/2 then                            // internal node
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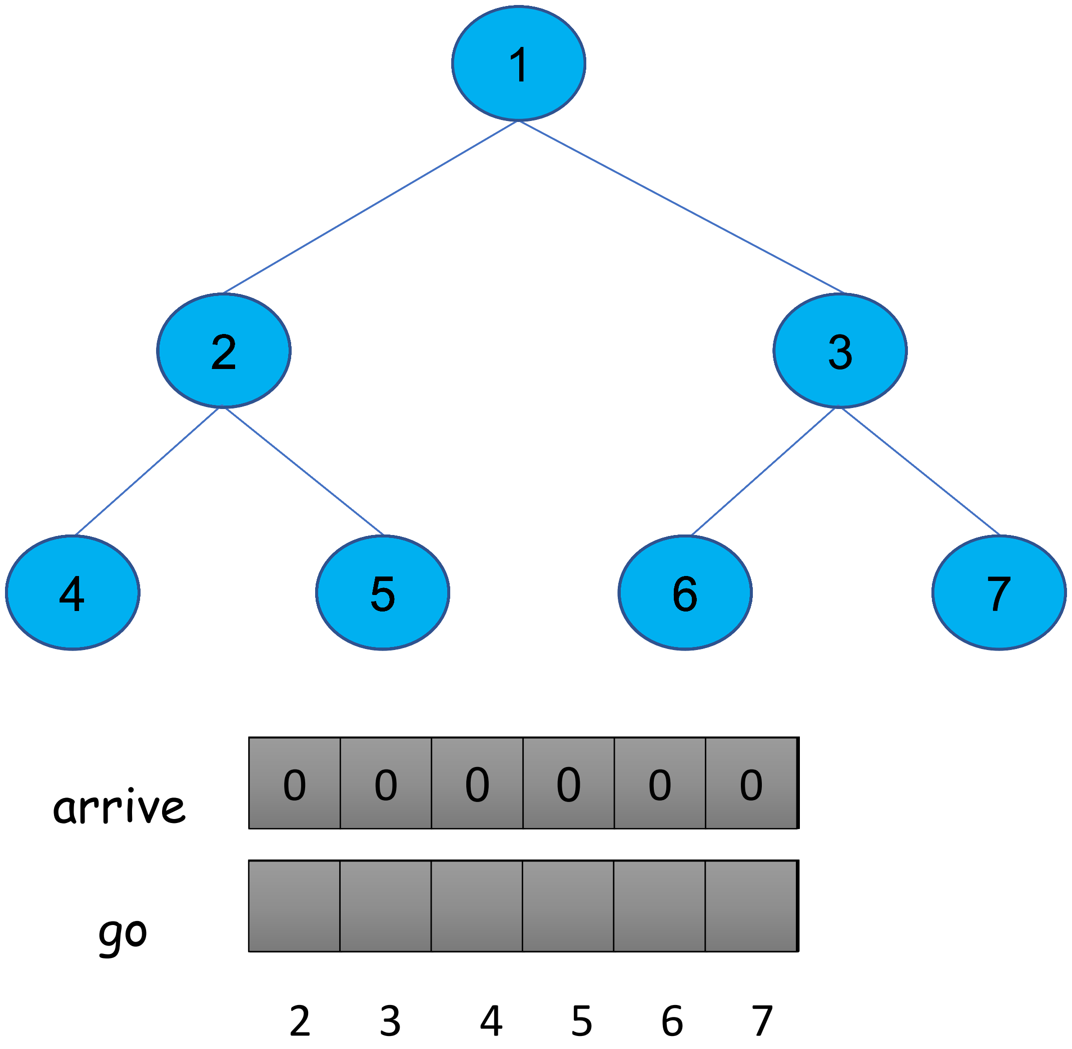
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0
    go[2i] = 1; go[2i+1] := 1
else                                                // leaf
    arrive[i] := 1
    await(go[i] = 1); go[i] := 0 fi
fi
```

At this point all non-root threads in some await(go) case

A Tree-based Barrier
Example Run for n=7 threads

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else                                                 // leaf
      arrive[i] := 1
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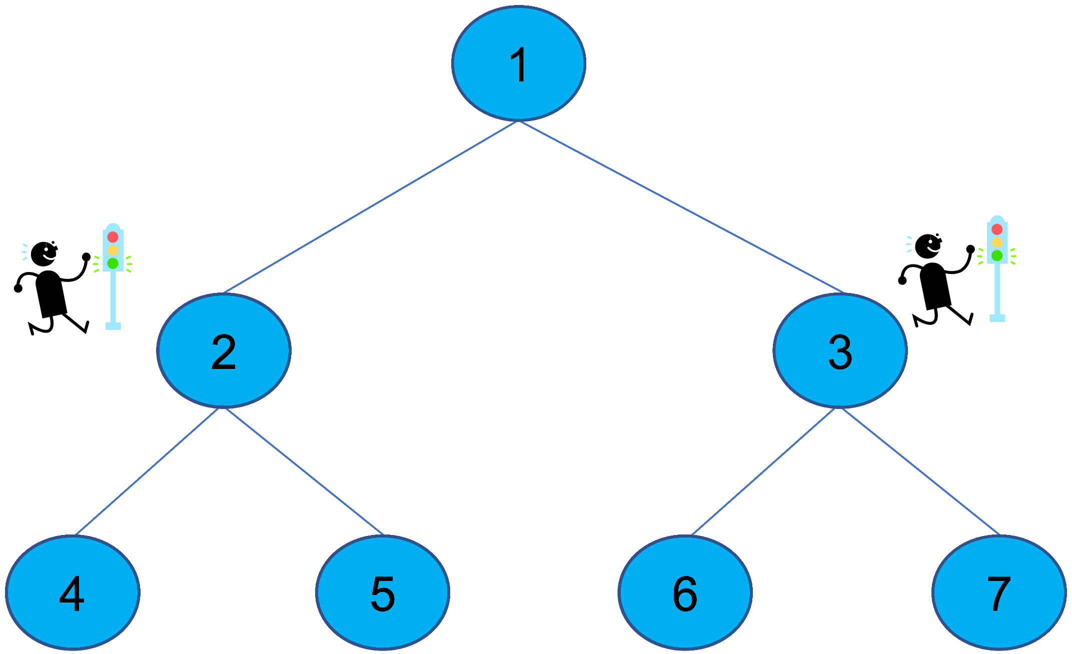
```

A Tree-based Barrier
Example Run for n=7 threads




```
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```
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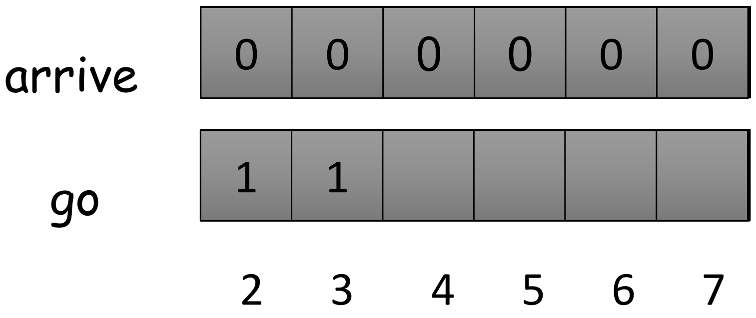
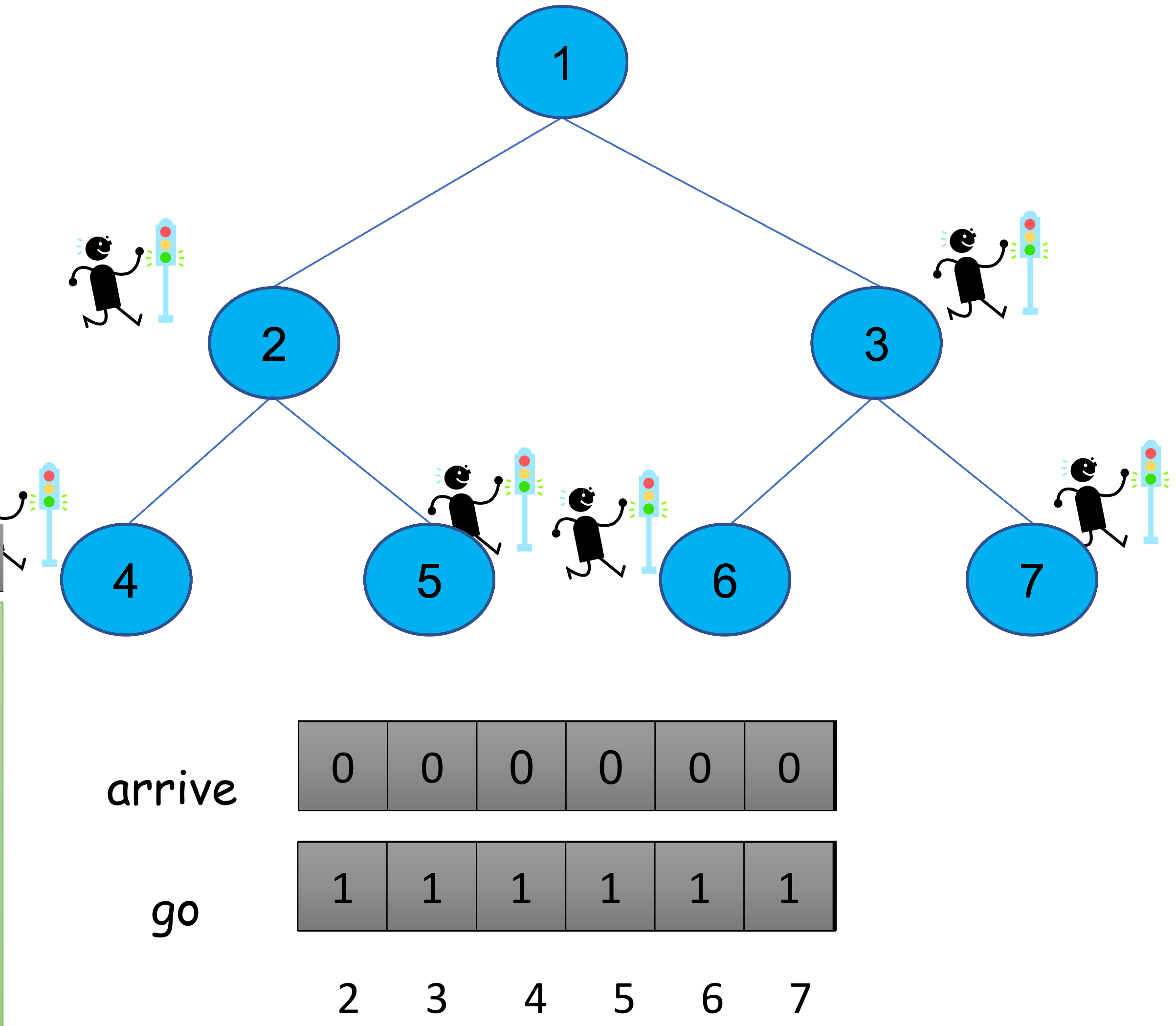


A Tree-based Barrier
Example Run for n=7 threads

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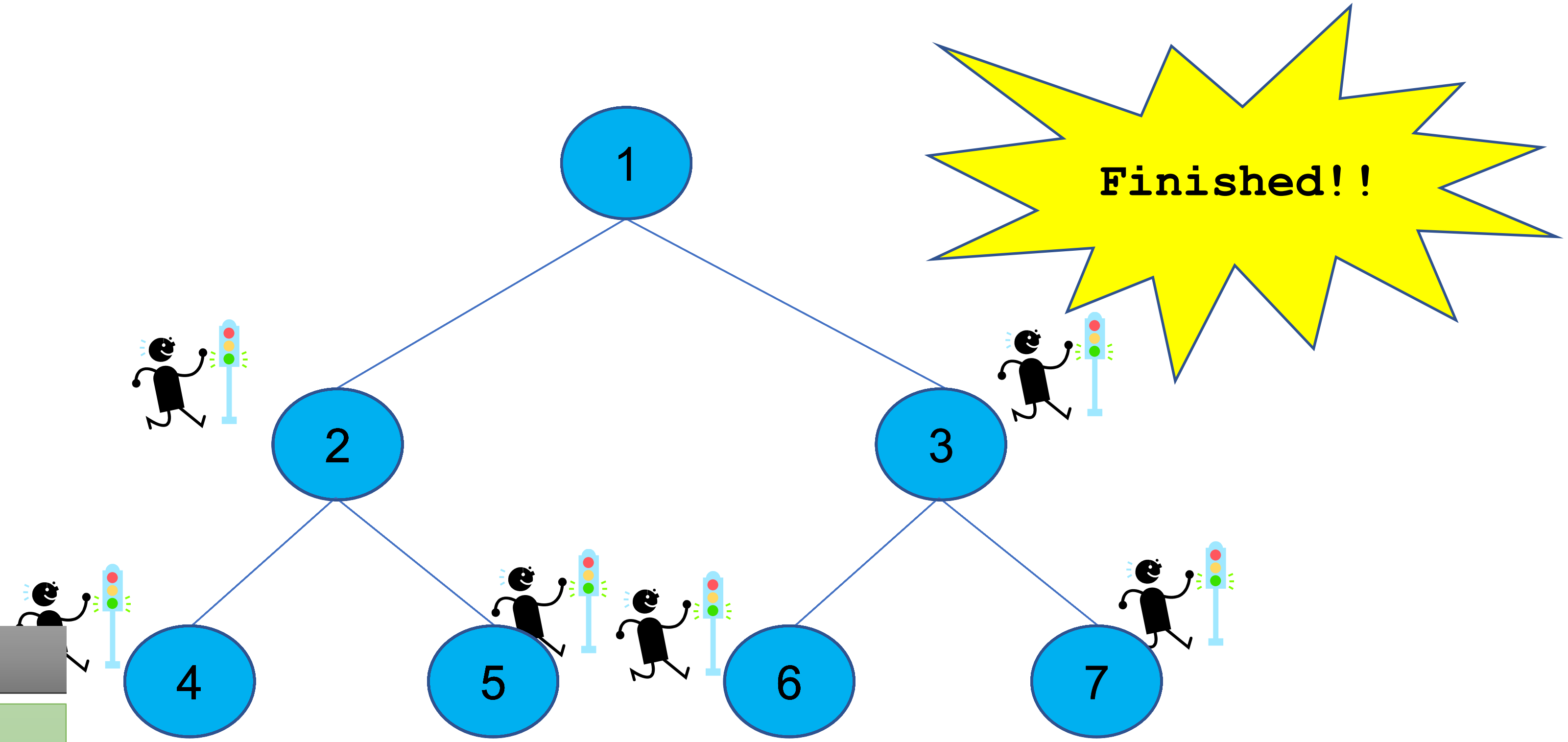
Example Run for n=7 threads



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else                                                // leaf
    arrive[i] := 1
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fi
```

arrive	0	0	0	0	0	0
go	1	1	1	1	1	1
	2	3	4	5	6	7

Tree Barrier Tradeoffs

- Pros:

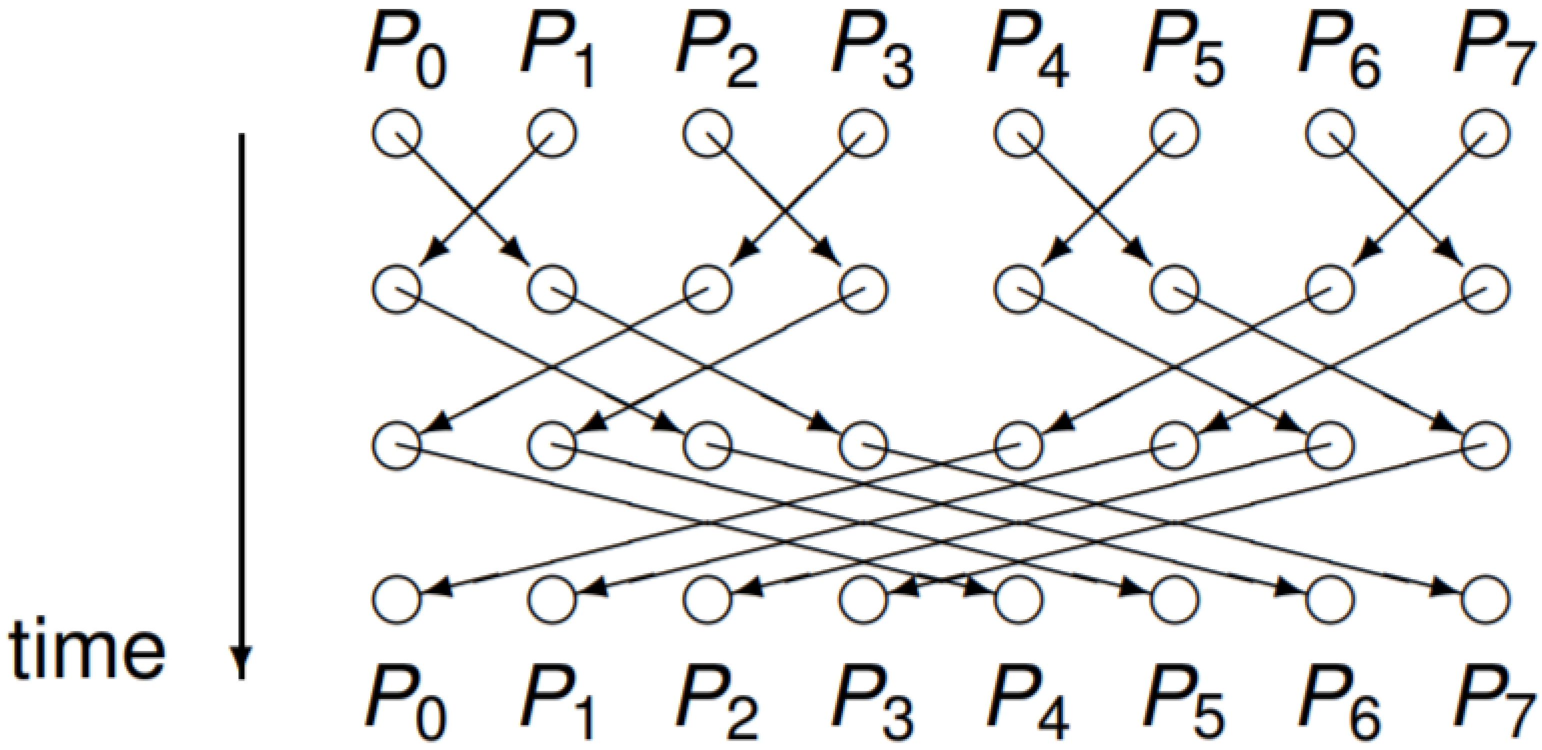
- Cons:

Tree Barrier Tradeoffs

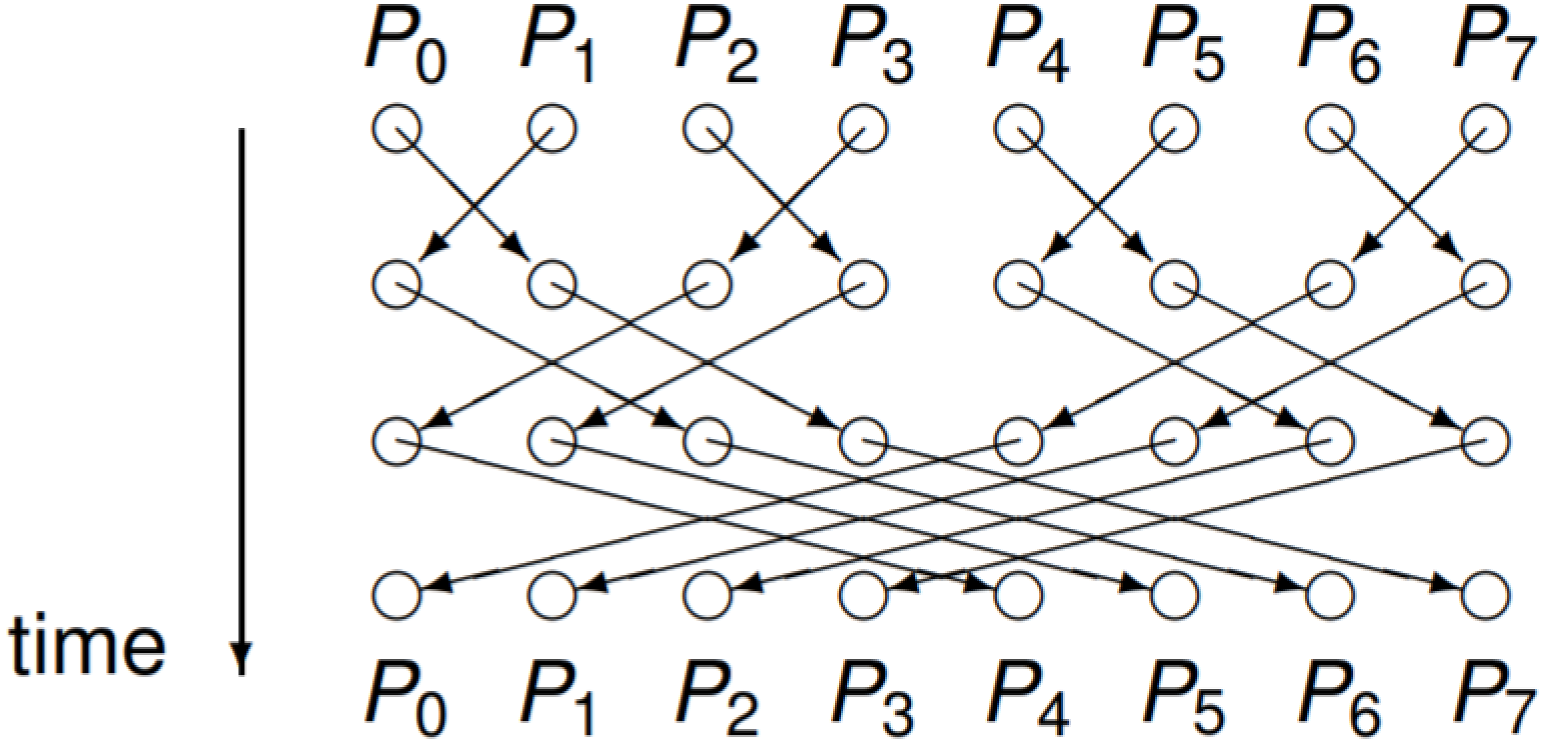
- Pros:
  - Low shared memory contention
    - No wait object is shared by more than 2 processes
    - Good for larger n
  - Fast – information from the root propagates after log(n) steps
  - Can use only atomic primitives (no special objects)
  - On some models:
    - each process spins on a locally accessible bit
    - # (remote memory ref.) = O(1) per process
- Cons:
  - Shared memory space complexity – O(n)
  - Asymmetric –all the processes don't the same amount of work
  - Corner cases for n != 2^k-1

Butterfly Barrier

Butterfly Barrier

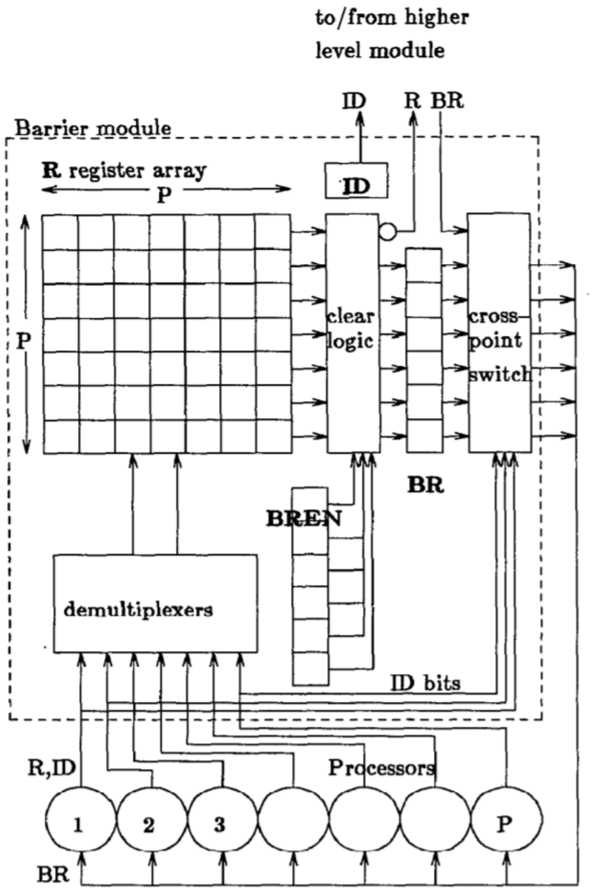


Butterfly Barrier



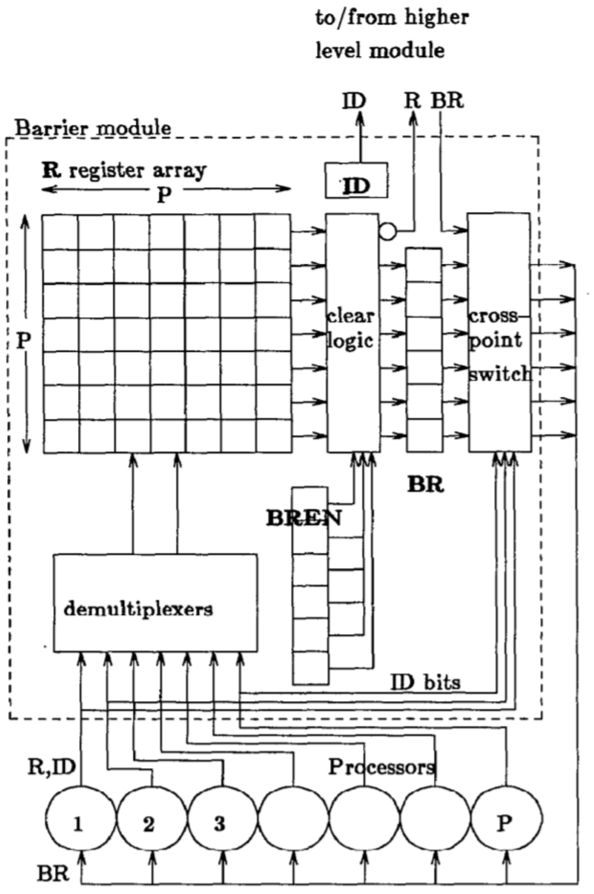
- When would this be preferable?

Hardware Supported Barriers



CPU

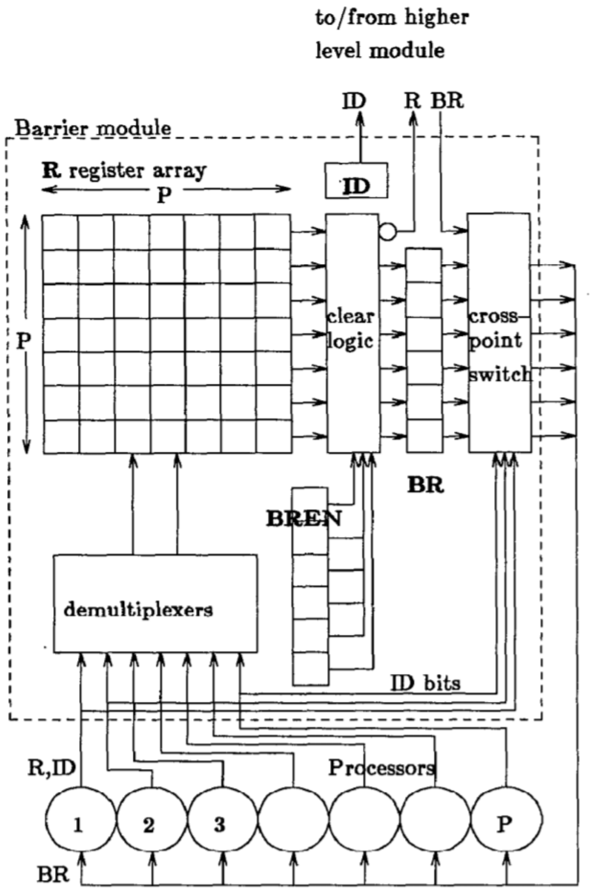
Hardware Supported Barriers



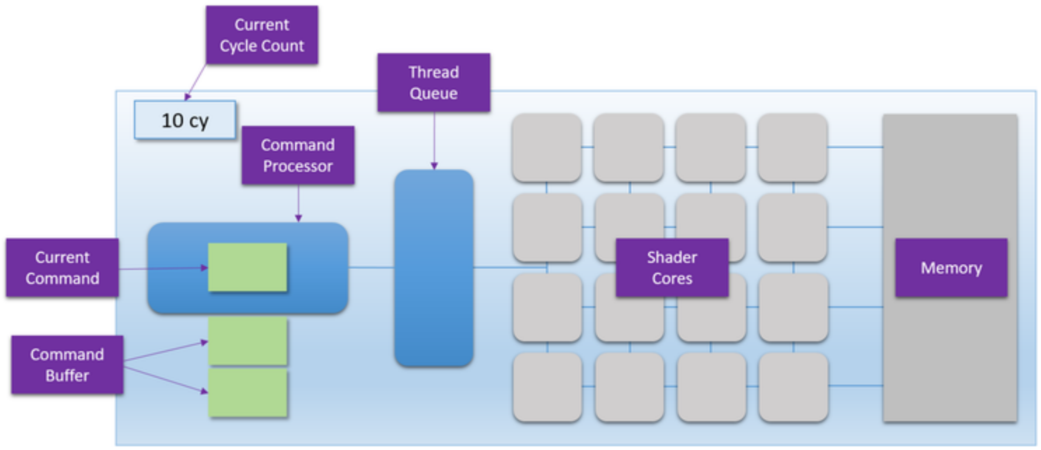
CPU

- When would this be useful?

Hardware Supported Barriers



CPU



GPU

- When would this be useful?

Barriers Summary

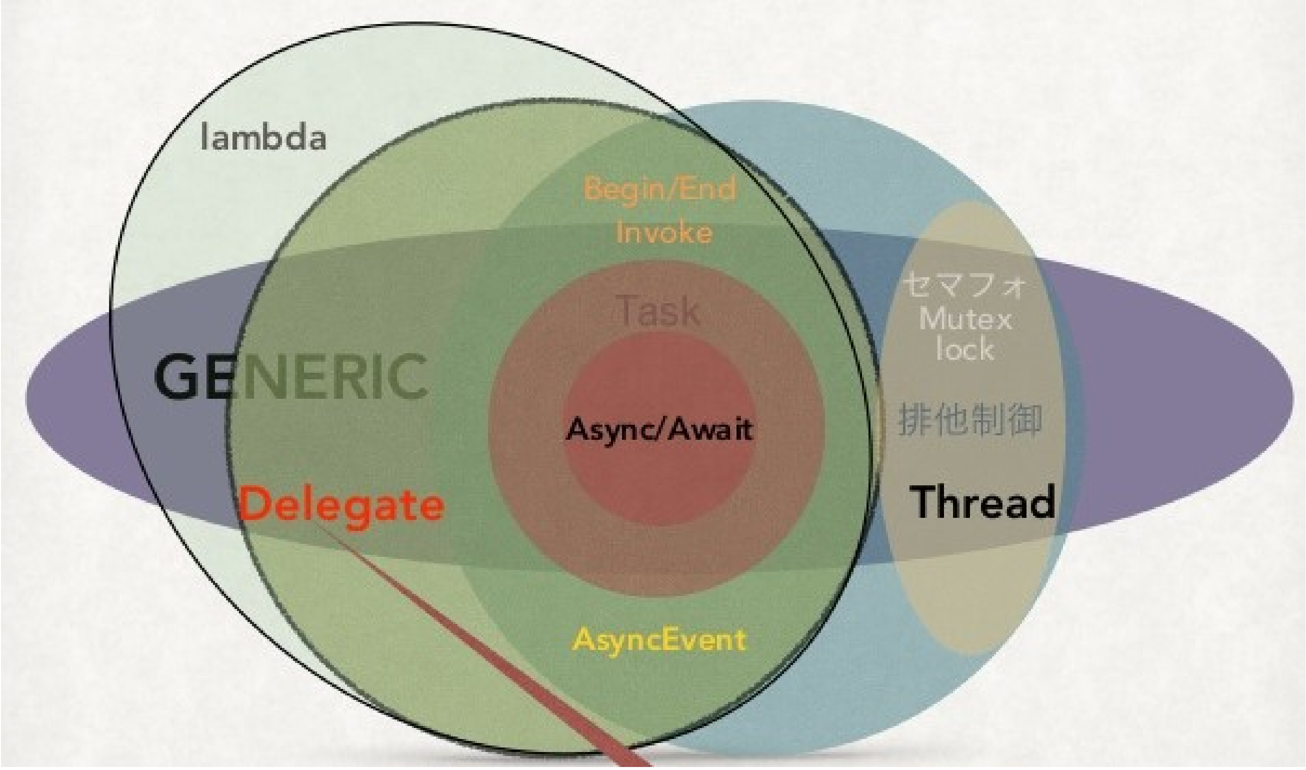
Seen:

- Semaphore-based barrier
- Simple barrier
  - Based on atomic fetch-and-increment counter
- Local spinning barrier
  - Based on atomic fetch-and-increment counter and go array
- Tree-based barrier

Not seen:

- Test-and-Set barriers
  - Based on test-and-test-and-set objects
  - One version without memory initialization
- See-Saw barrier
- Book has condition barriers

Asynchronous Programming
Events, Promises, and Futures



Programming Models for Concurrency

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- Hardware execution model:

Programming Models for Concurrency

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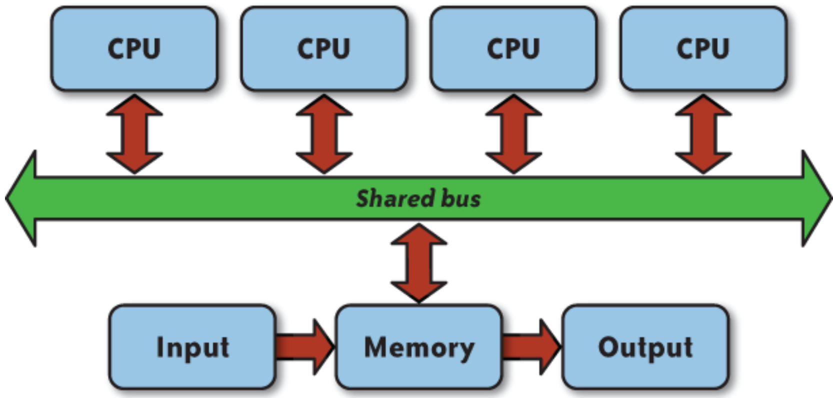

Programming Models for Concurrency

- Hardware execution model:
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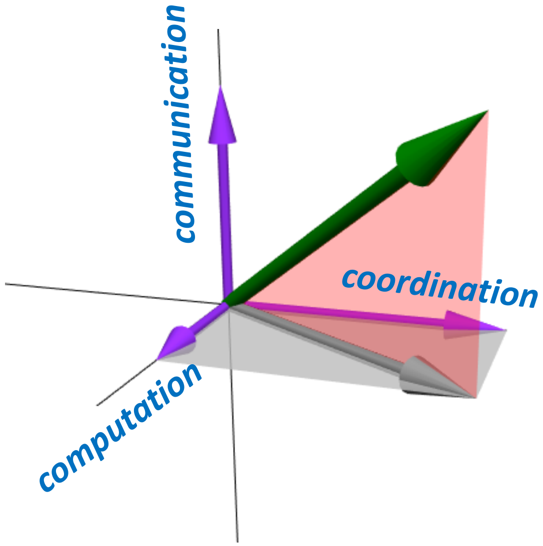
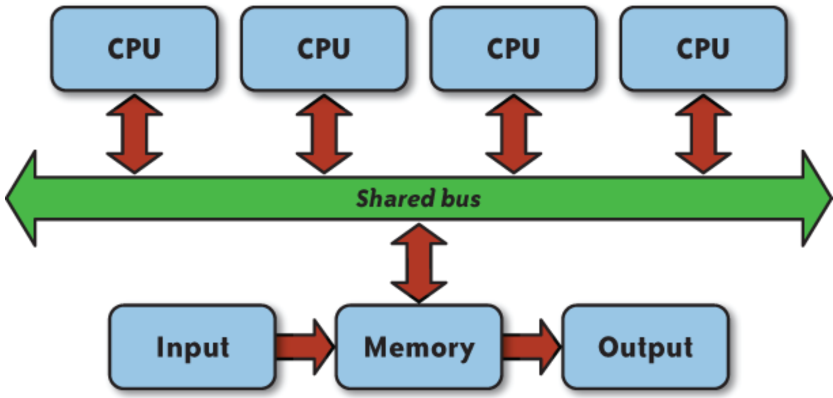
- Programming model dimensions:
  - How to specify computation
  - How to specify communication
  - How to specify coordination/control transfer





Programming Models for Concurrency

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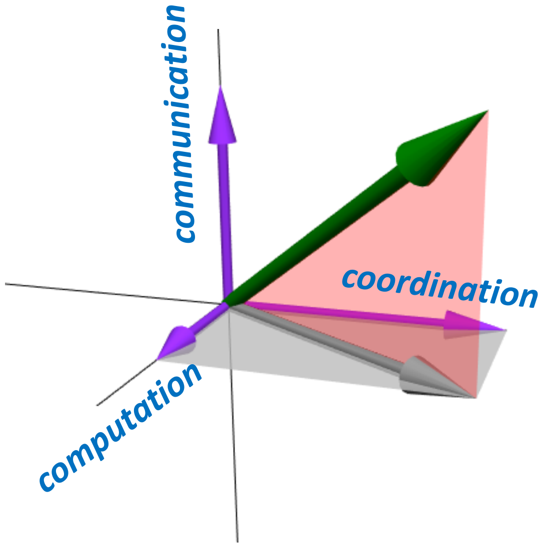
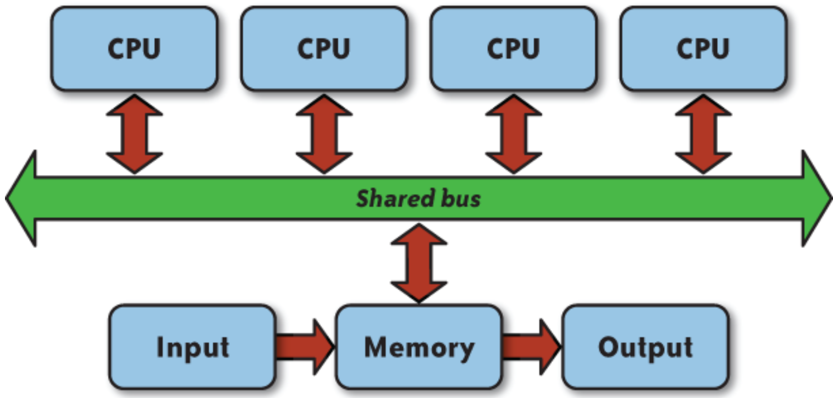
  - Preemption vs Non-preemption





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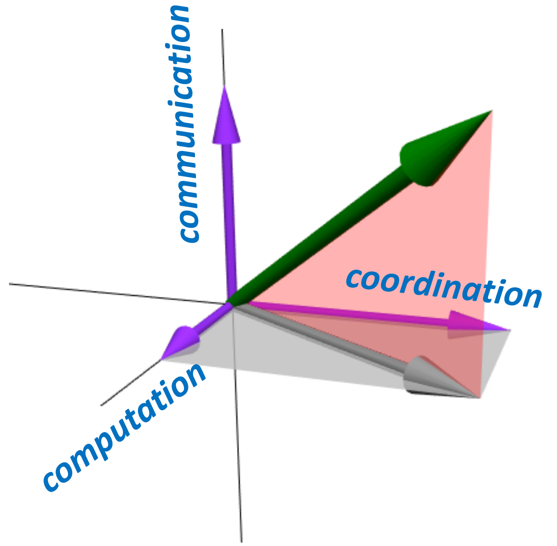

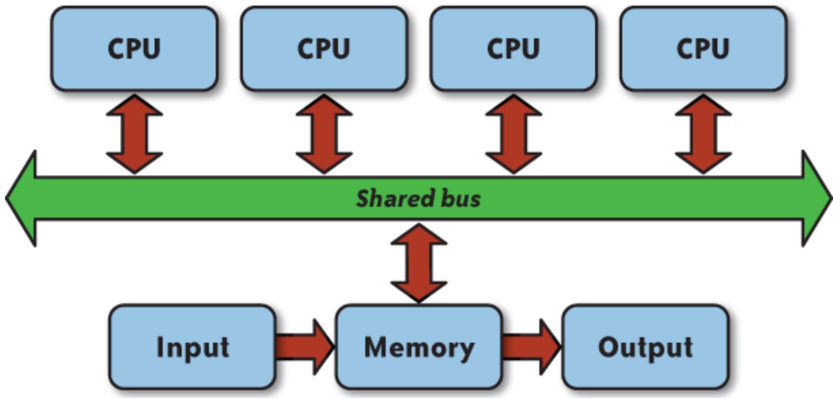

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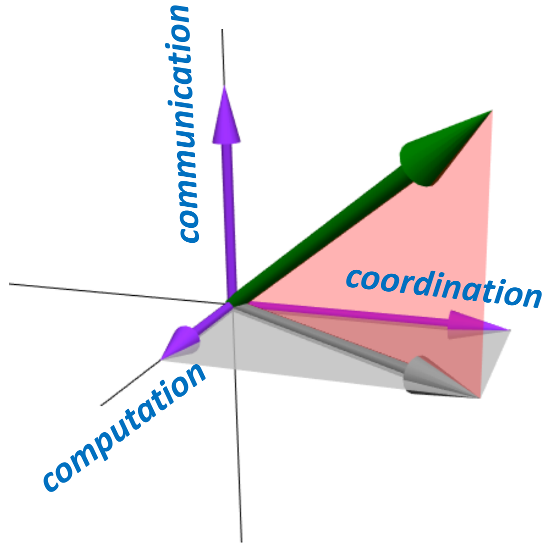
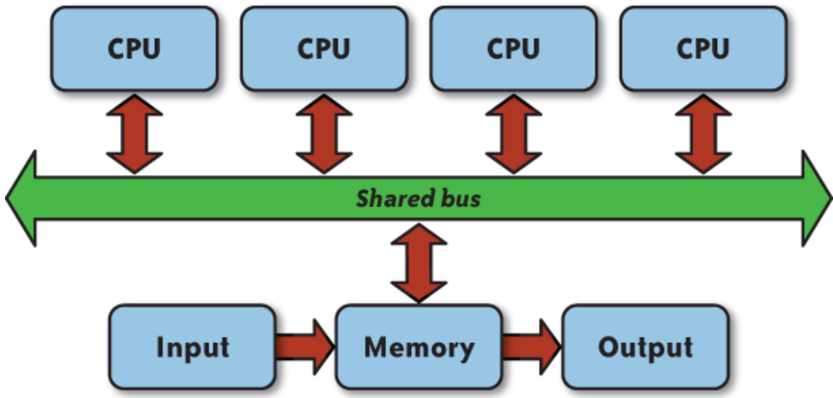
Futures & Promises touch all three dimension





Futures & Promises

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- Time-dependent states:
  - **Completed/determined**
    - Computation complete, value concrete
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    - Computation not complete yet

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- Values *that will eventually become available*
- Time-dependent states:
  - **Completed/determined**
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  - **Incomplete/undetermined**
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- Construct (future X)
  - immediately returns value
  - concurrently executes X

Java Example

```java
static void runAsyncExample() {
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        assertTrue(Thread.currentThread().isDaemon());
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- runAsync() immediately returns a waitable object (cf)
- Where (on what thread) does the lambda expression run?

Futures and Promises:

Why two kinds of objects?

```
future<int> f1 = async(foo1);
...
int result = f1.get();
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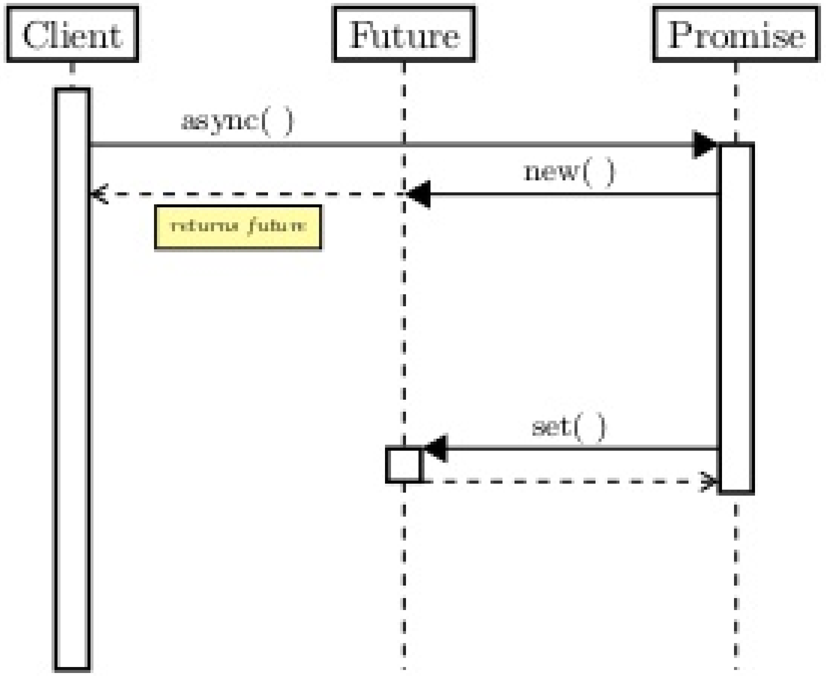

Futures and Promises:

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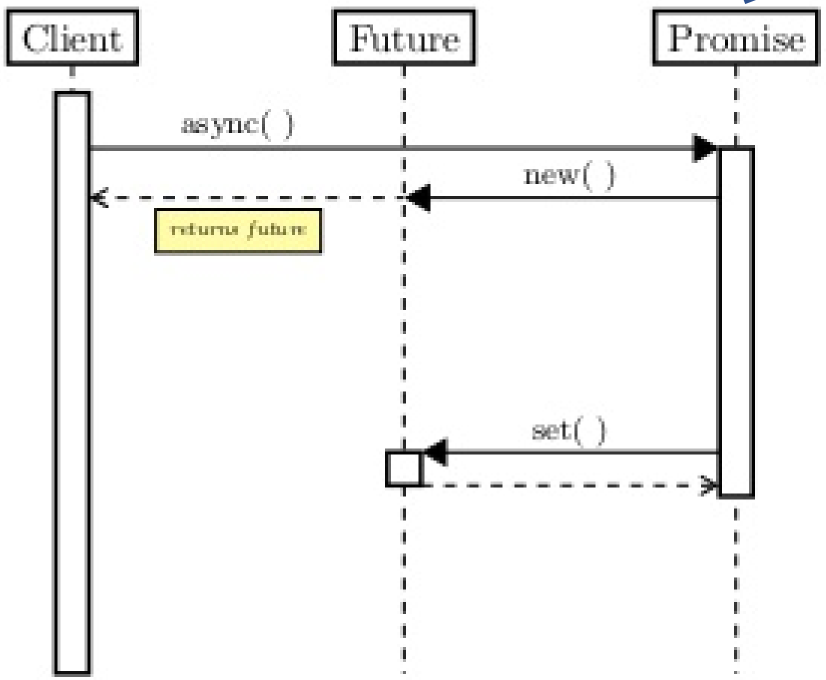
Promise: “thing to be done”

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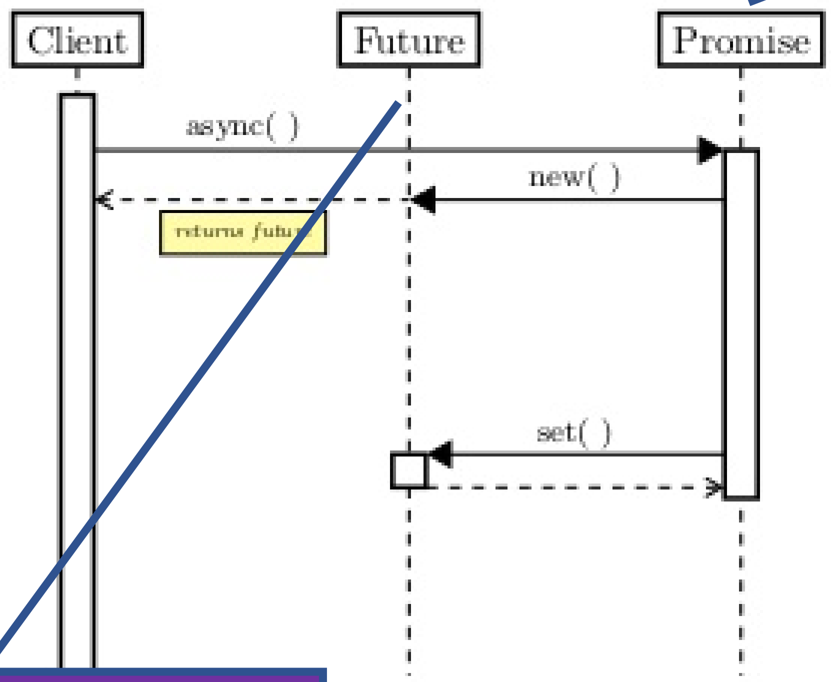


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(something to give caller)

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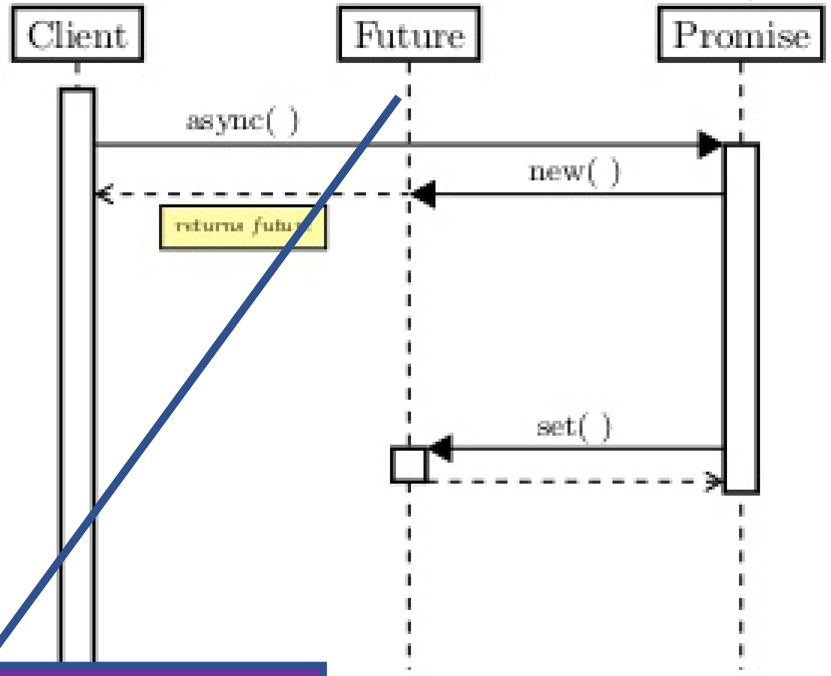


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Promise to do something in the future

Futures vs Promises

- **Future:** read-only reference to uncompleted value
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- Promises *complete* the future with:
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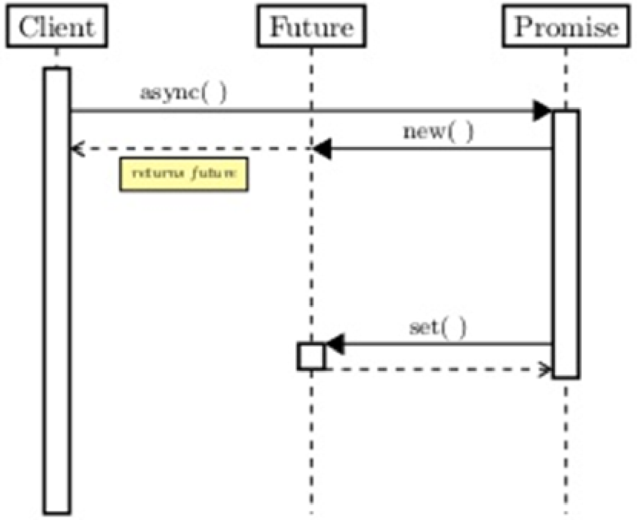

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Algol	Thunk	Address of async result
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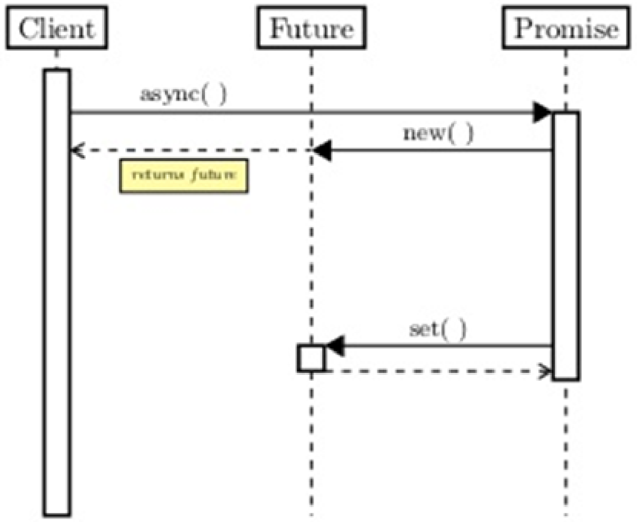
C#/.NET	TaskCompletionSource<T>	Task<T>
JavaScript	Deferred	Promise
C++	std::promise	std::future



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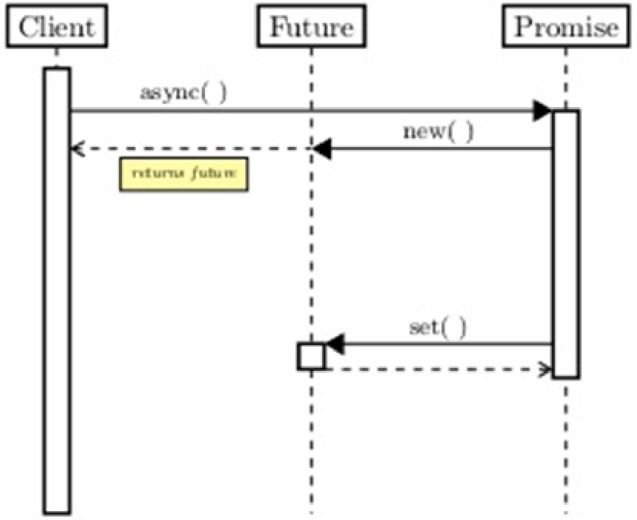

Futures vs Promises

Mnemonic:
Promise to ***do*** something
Make a promise ***for*** the future

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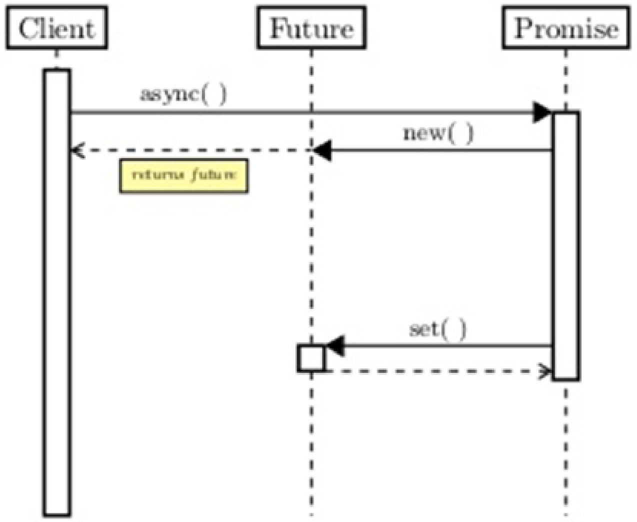

Putting Futures in Context

My unvarnished opinion

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  - Compiler: abstractions are ***language-level objects***
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Compromise Programming Model between:

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- Event-based programming
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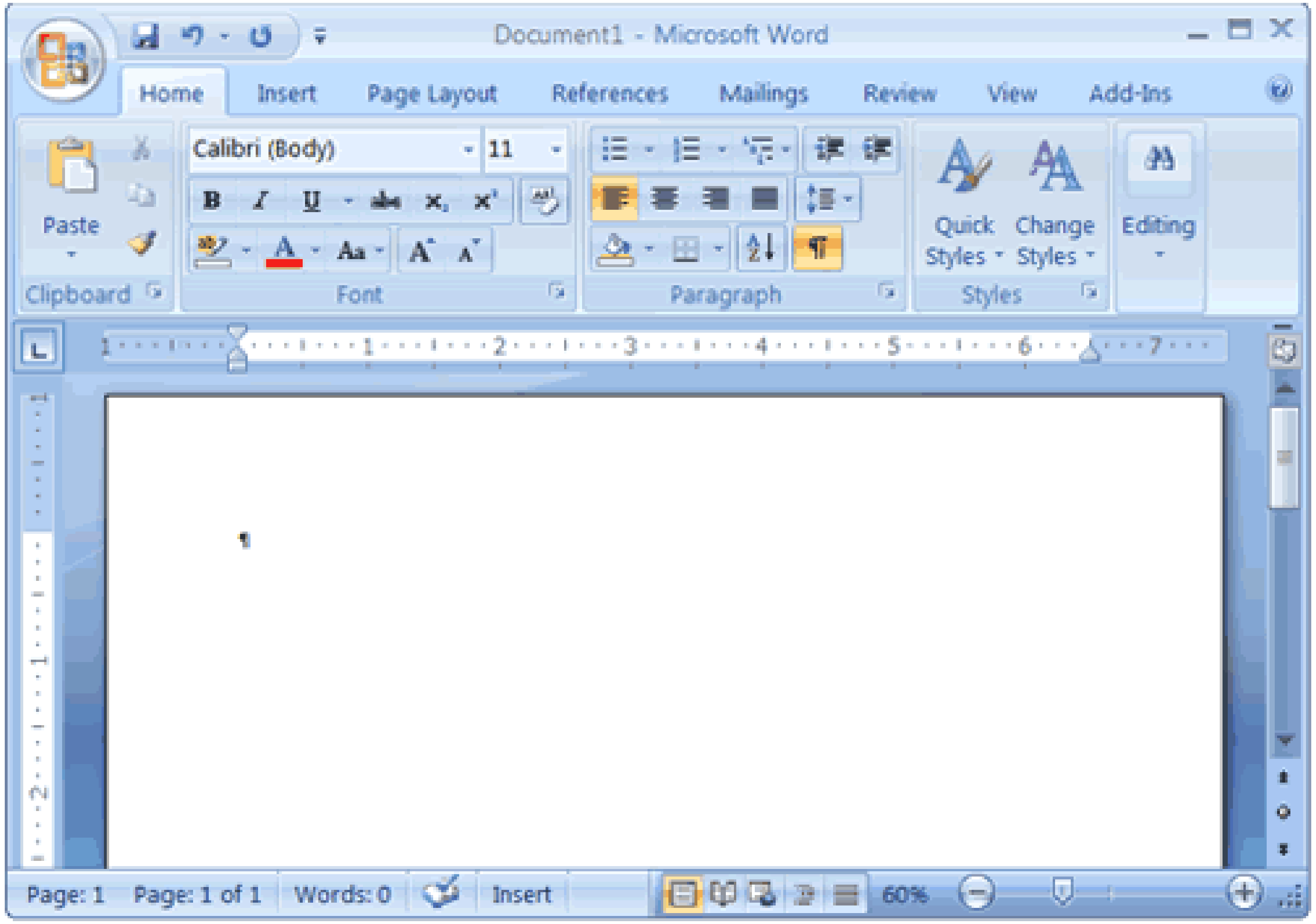
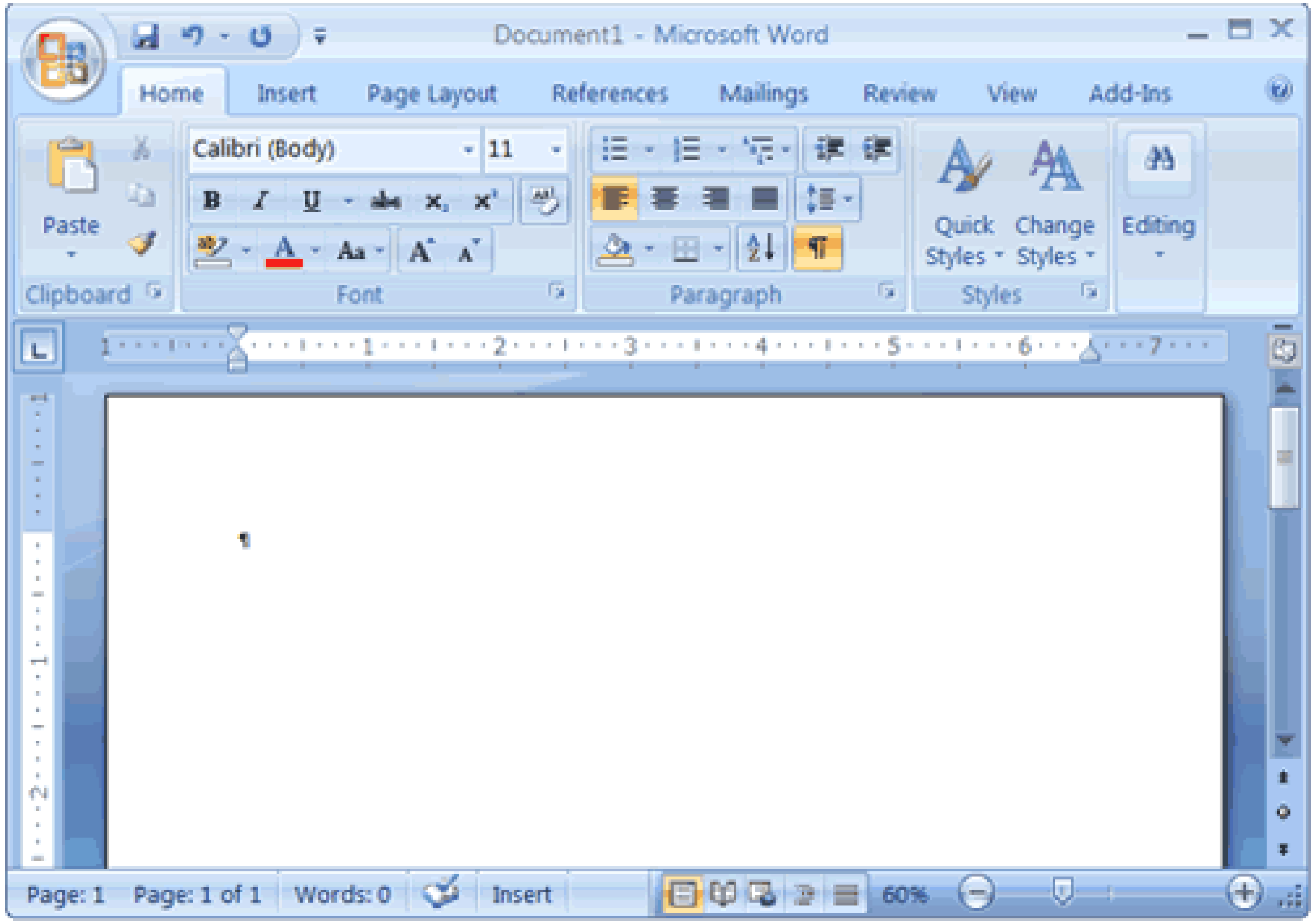
Events vs. Threads!

GUI Programming

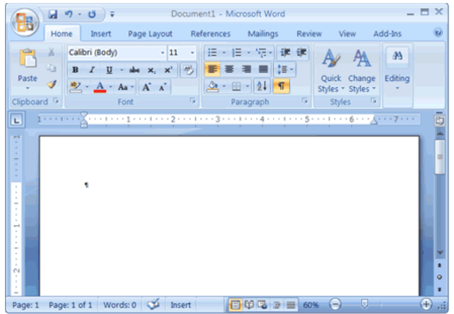


GUI Programming




```
do {
  WaitForSomething();
  RespondToThing();
} until(forever);
```

GUI Programming

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int WINAPI WinMain(HINSTANCE hInstance, HINSTANCE hPrevInstance,
    LPSTR lpCmdLine, int nCmdShow)
{
    WNDCLASSEX wc;
    HWND hwnd;
    MSG Msg;

    //Step 1: Registering the Window Class
    wc.cbSize        = sizeof(WNDCLASSEX);
    wc.style         = 0;
    wc.lpfnWndProc   = WndProc;
    wc.cbClsExtra    = 0;
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    wc.hInstance     = hInstance;
    wc.hIcon         = LoadIcon(NULL, IDI_APPLICATION);
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    wc.hbrBackground = (HBRUSH)(COLOR_WINDOW+1);
    wc.lpszMenuName  = NULL;
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    if(!RegisterClassEx(&wc))
    {
        MessageBox(NULL, "Window Registration Failed!", "Error!",
            MB_ICONEXCLAMATION | MB_OK);
        return 0;
    }

    // Step 2: Creating the Window
    hwnd = CreateWindowEx(
        WS_EX_CLIENTEDGE,
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    if(hwnd == NULL)
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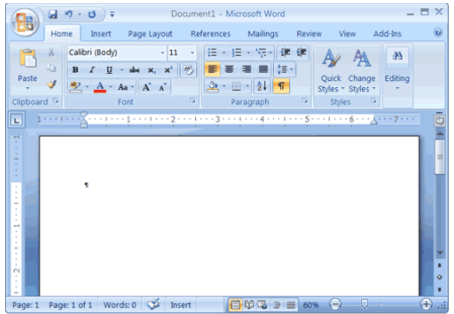

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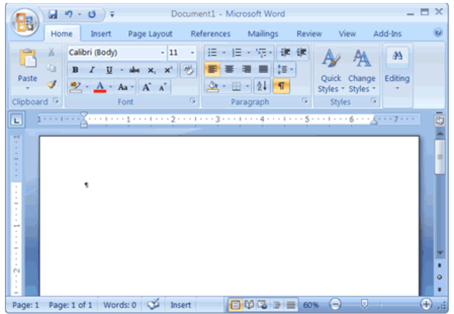


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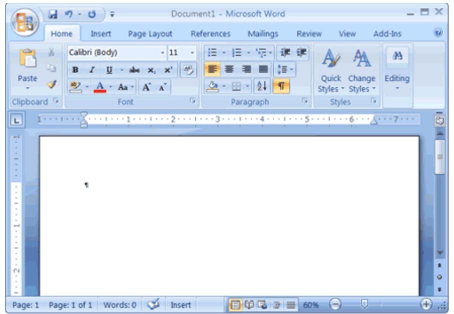


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        //break;
        //case WM_PAINT:
          // draw our window - note: you must paint something here or not trap it!
        //break;
        case WM_DESTROY:
             PostQuitMessage(0);
        break;
        default:
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            return DefWindowProc(hWnd, message, wParam, lParam);
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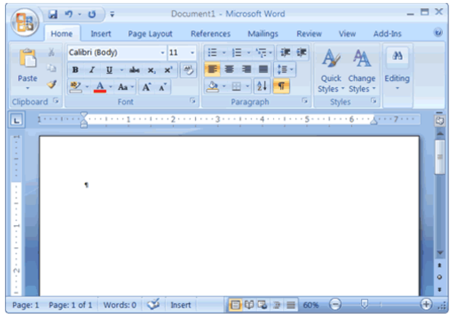


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            return DefWindowProc(hWnd, message, wParam, lParam);
}
```

Hex	Decimal	Symbolic
0000	0	WM_NULL
0001	1	WM_CREATE
0002	2	WM_DESTROY
0003	3	WM_MOVE
0005	5	WM_SIZE
0006	6	WM_ACTIVATE
0007	7	WM_SETFOCUS
0008	8	WM_KILLFOCUS
000a	10	WM_ENABLE
000b	11	WM_SETREDRAW
000c	12	WM_SETTEXT
000d	13	WM_GETTEXT
000e	14	WM_GETTEXTLENGTH
000f	15	WM_PAINT
0010	16	WM_CLOSE
0011	17	WM_QUERYENDSESSION
0012	18	WM_QUIT
0013	19	WM_QUERYOPEN
0014	20	WM_ERASEBKGND

```
ION);
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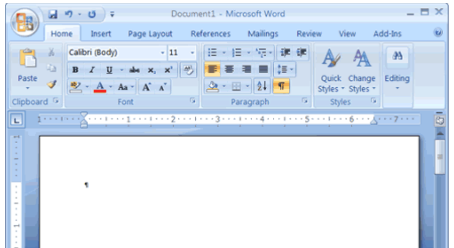
ed!", "Error!",
, "Error!",
        TranslateMessage(&Msg);
        DispatchMessage(&Msg);
    }
    return Msg.wParam;
}
```



```
int WINAPI WinMain(HINSTANCE hInstance, HINSTANCE hPrevInstance,
    LPSTR lpCmdLine, int nCmdShow)
{
    WNDCLASSEX wc;
    HWND hwnd;
    MSG Msg;
```

GUI programming

Over 1000 last time I checked!

```
switch (message)
{
        //case WM_COMMAND:
          // handle menu selections etc.
        //break;
        //case WM_PAINT:
          // draw our window - note: you must paint something here or not
        //break;
        case WM_DESTROY:
             PostQuitMessage(0);
        break;
        default:
            // We do not want to handle this message so pass back to Winc
            // to handle it in a default way
            return DefWindowProc(hWnd, message, wParam, lParam);
}
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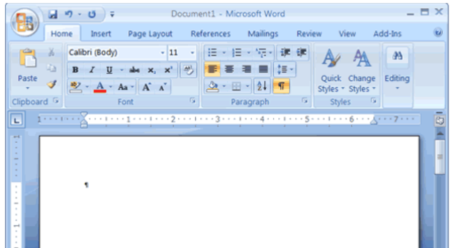

GUI programming

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{
    WNDCLASSEX wc;
    HWND hwnd;
    MSG Msg;
```

Over 1000 last time I checked!

```
void OnMove() { … }
void OnSize() { … }

void OnPaint() { … }
```

```
switch (message)
{
        //case WM_COMMAND:
          // handle menu select
        //break;
        //case WM_PAINT:
          // draw our window -                    r not
        //break;
        case WM_DESTROY:
             PostQuitMessage(0);
        break;
        default:
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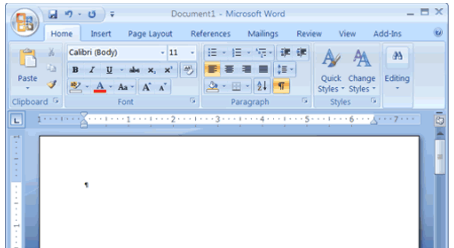

GUI Programming Distilled

```
winmain(...) {
  while(true) {
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      case WM_DONE: return;
      }
  }
}
```

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Pros

GUI Programming Distilled

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Pros

- Simple imperative programming

GUI Programming Distilled

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Pros

- Simple imperative programming
- Good fit for uni-processor

GUI Programming Distilled

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Pros

- Simple imperative programming
- Good fit for uni-processor

Cons

- Awkward/verbose

GUI Programming Distilled

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    }
  }
}
```

Pros

- Simple imperative programming
- Good fit for uni-processor

Cons

- Awkward/verbose
- **Obscures available parallelism**

GUI Programming Distilled

```
winmain(...) {
  while(true) {
      message = GetMessage();
      switch(message) {
      case WM_LONGRUNNING_CPU_HOG: HogCPU(); break;
      case WM_HIGH_LATENCY_IO: BlockForALongTime(); break;
      case WM_DO_QUICK_IMPORTANT_THING: HopeForTheBest(); break;
      }
  }
}
}
```

Pros

- Simple imperative programming
- Good fit for uni-processor

Cons

- Awkward/verbose
- **Obscures available parallelism**

GUI Programming Distilled

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    case WM_DONE: return;
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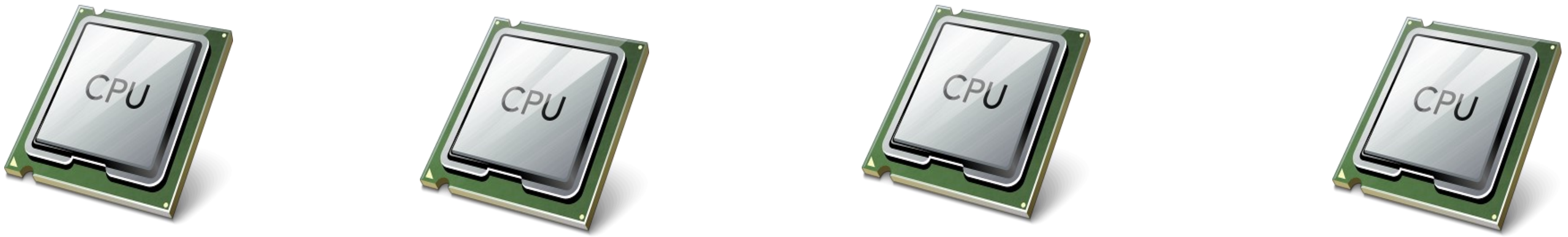
  }
}
```

How can we parallelize this?



Parallel GUI Implementation 1

```
winmain(...) {
  while(true) {
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      switch(message) {
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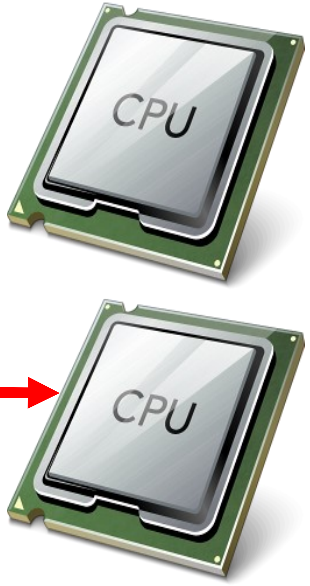

Parallel GUI Implementation 1

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        }
    }
}
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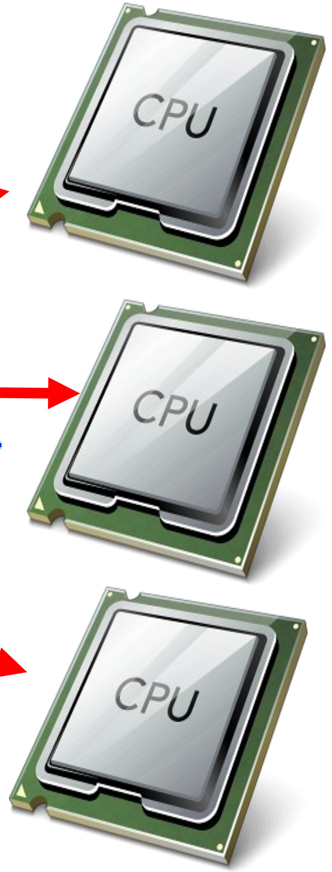
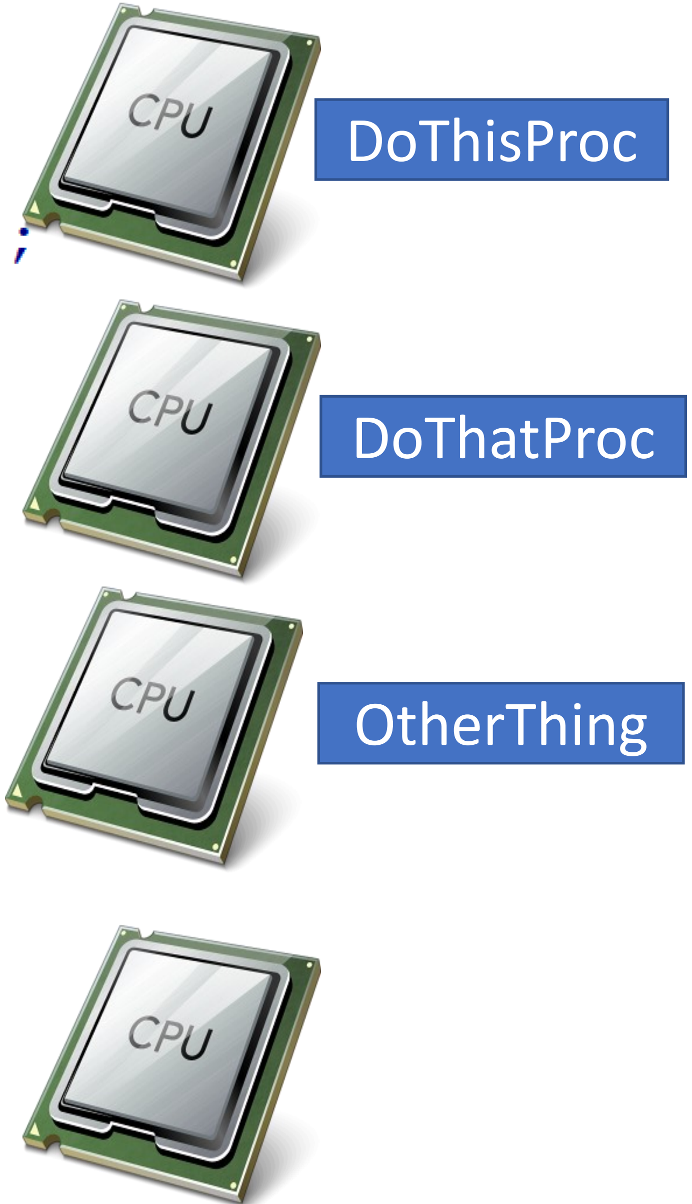


Parallel GUI Implementation 1

```
winmain() {
    pthread_create(&tids[i++], DoThisProc);
    pthread_create(&tids[i++], DoThatProc);
    pthread_create(&tids[i++], DoOtherThingProc);
    for(j=0; j<i; j++)
        pthread_join(&tids[j]);
}

DoThisProc() {
    while(true){
        if(ThisHasHappened)
            DoThis();
    }
}
```



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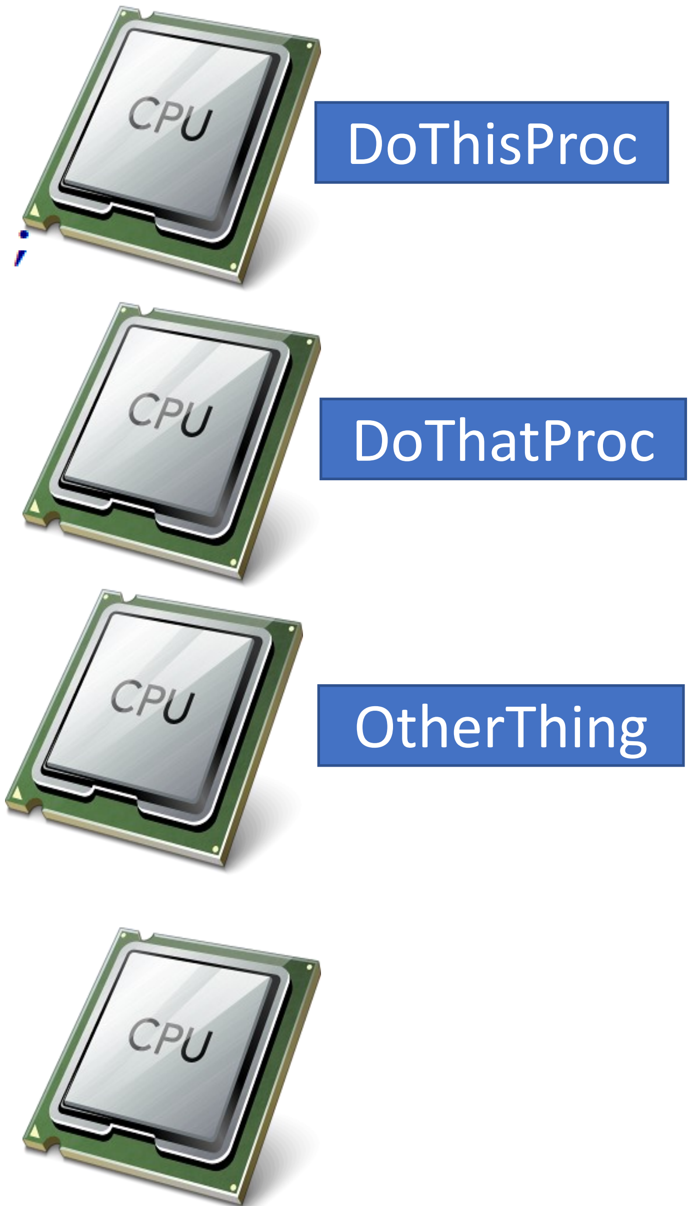
    for(j=0; j<i; j++)
        pthread_join(&tids[j]);
}
```

Pros/cons?

```
DoThisProc() {
    while(true){
        if(ThisHasHappened)
            DoThis();
    }
}
```



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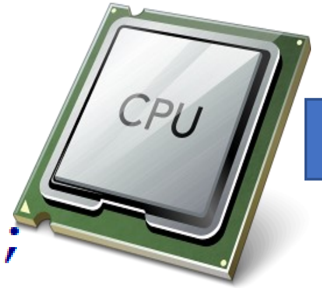
    for(j=0; j<i; j++)
        pthread_join(&tids[j]);
}

DoThisProc() {
    while(true){
        if(ThisHasHap
            DoThis();
    }
}
```

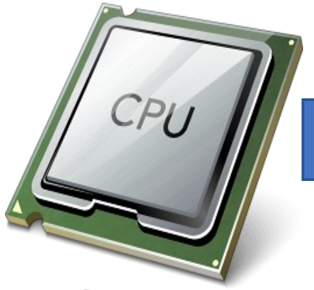
Pros/cons?

Pros:
- Encapsulates parallel work

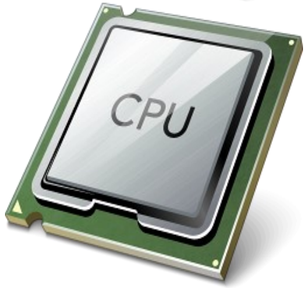
Cons:
- Obliterates original code structure
- How to assign handlers→CPUs?
- Load balance?!?
- Utilization



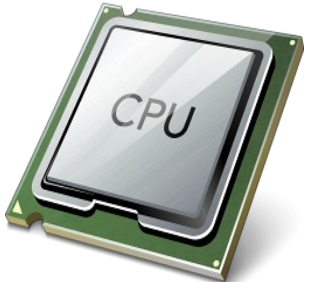
DoThisProc



DoThatProc



OtherThing



Parallel GUI Implementation 2

```
winmain() {
    for(i=0; i<NUMPROCS; i++)
        pthread_create(&tids[i], HandlerProc);
    for(i=0; i<NUMPROCS; i++)
        pthread_join(&tids[i]);
}
```

```
threadproc(...) {
  while(true) {
    message = GetMessage();
    switch(message) {
    case WM_THIS: DoThis();
    case WM_THAT: DoThat();
    }
  }
}
```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threadproc(...) {
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Parallel GUI Implementation 2

Pros/cons?

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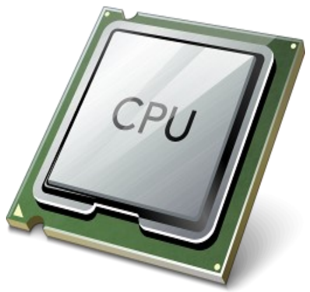

Parallel GUI Implementation 2

```
winmain() {
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        pthread_create(&tids[i], H
    for(i=0; i<NUMPROCS; i++)
        pthread_join(&tids[i]);
}
```

Pros/cons?

Pros:
- Preserves programming model
- Can recover some parallelism

Cons:
- Workers still have same problem
- How to load balance?
- Shared mutable state a problem

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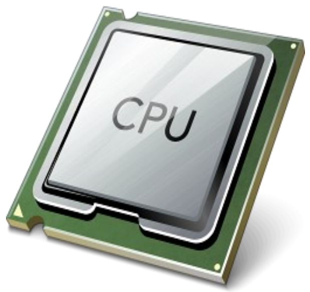

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Extremely difficult to solve without changing the whole programming model…so ***change it***

Questions?