Beyond “Nested Parallelism”

<u>Futures</u> are a way to pipeline computations while still having “deterministic” parallel programs (i.e. ones that don’t depend on the schedule).

Available in Java concurrency library.

Futures

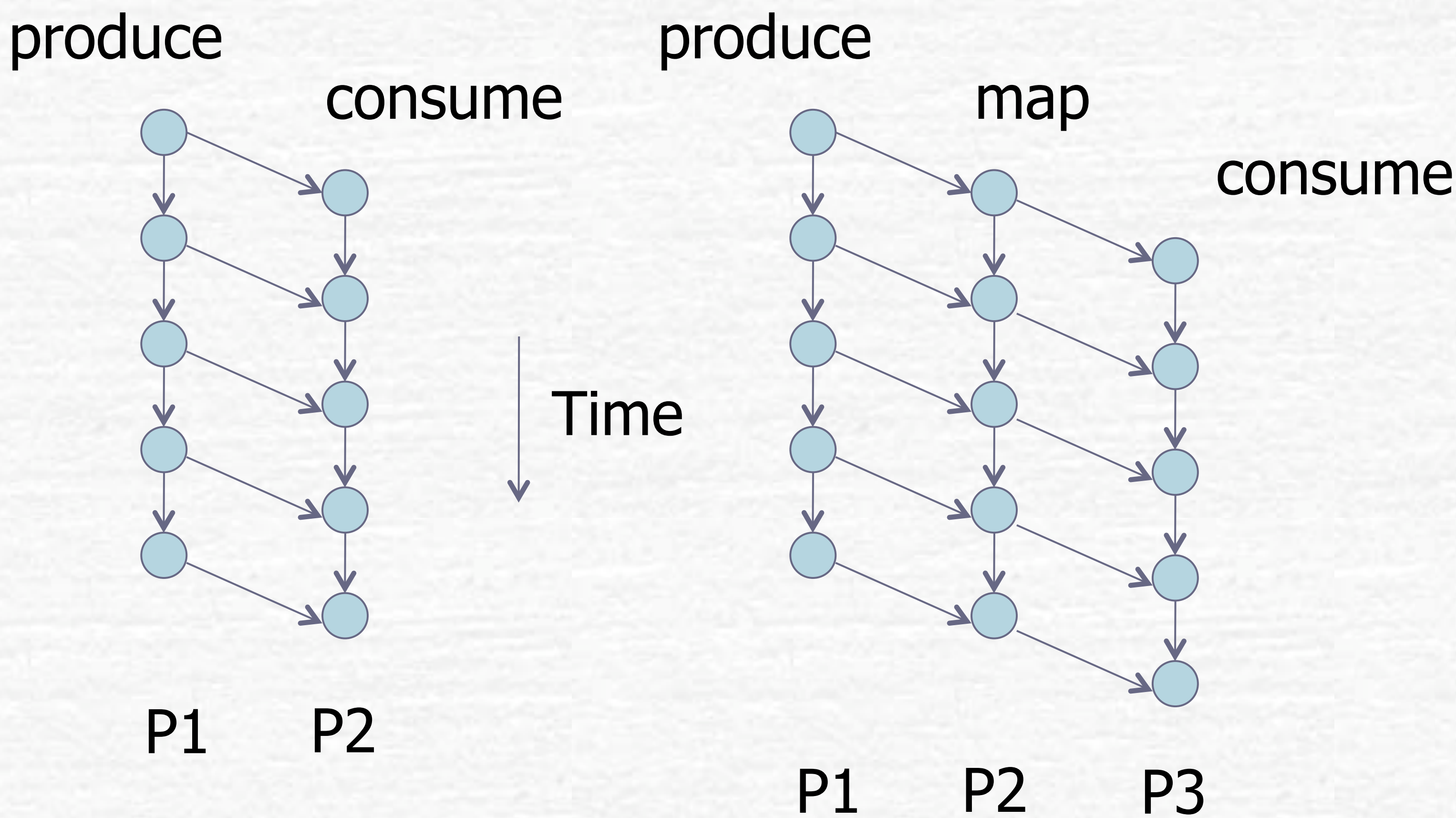
`future e` : generate a "future" cell and a parallel task to evaluate e. Return the cell immediately. When e is done, it places its value in the "future" cell.

`? e` : This operation (called "touch") gets the value out of the cell.   If the value is not ready, it waits until it is and then returns the value.

Consumer Producer

```
fun produce(0) = nil
  | produce(n) = f(n):: future produce(n-1);

fun consume(nil,state) = state
  | consume(h::t,state) =
        consume(?t,g(h,state);

fun map(nil) = nil
  | map(h::t) = h(t)::future map(?t);
```

The producer and consumer can work in parallel in a pipelined fashion.


produce
consume
Time
P1
P2
produce
map
consume
P1
P2
P3

Consumer Producer

```
fun ints(0) = 0
  | ints(n) = n :: future ints(n-1)

fun sum(nil,accum) = accum
  | sum(h::t,accum) = sum(?t,h+accum)

sum(ints(1000))
```

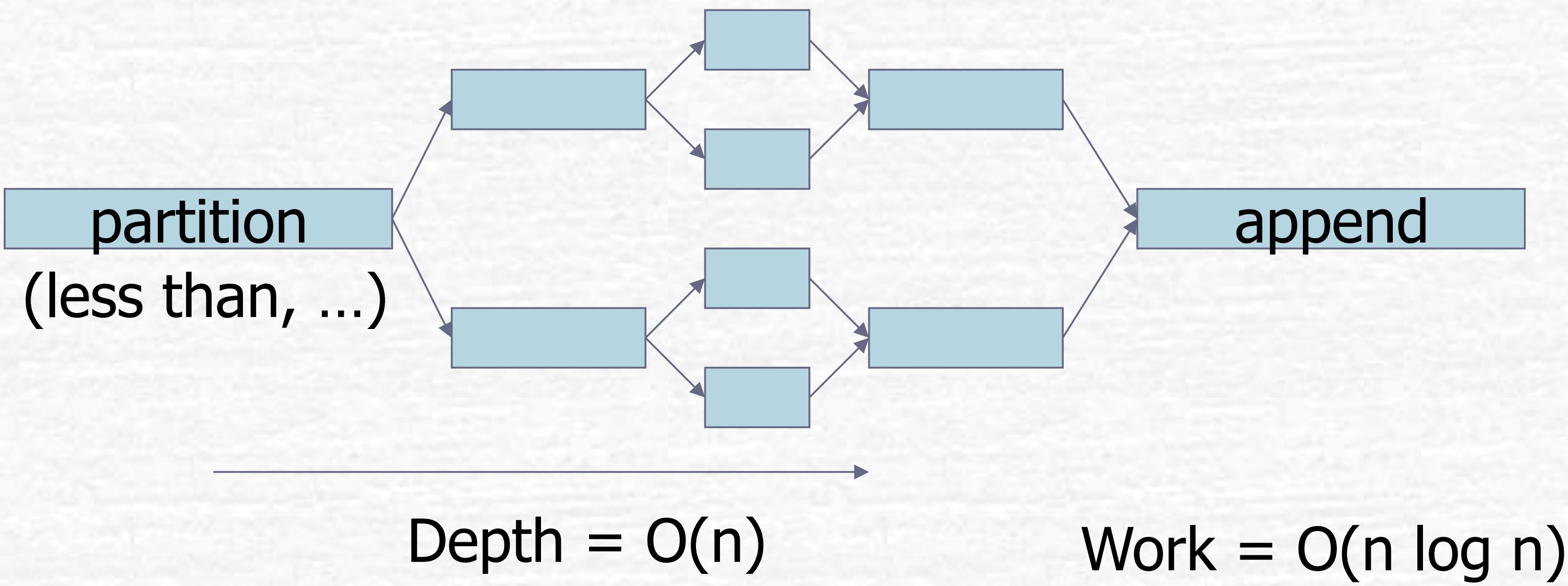
When there are no race conditions futures have a sequential semantics (they always return the same thing as if they were ignored)

Quicksort with Futures

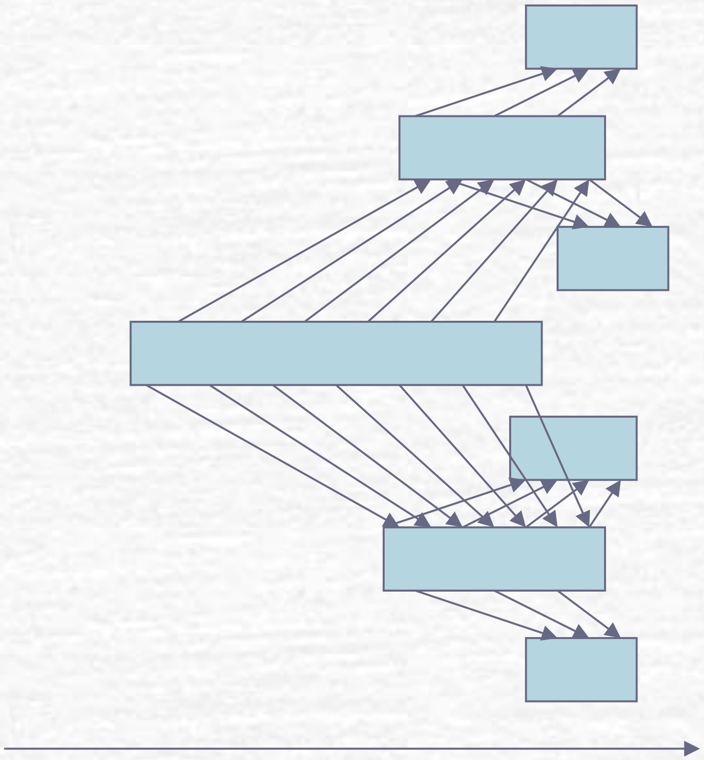
```
fun filter f nil = nil
  | filter f h::t =
 if f(h)
 then h::(future (filter f ?t))
 else filter f ?t;

fun qsort(nil,rest)   = rest
  | qsort(h::t,rest) =
 let val L1 = filter (fn b => b < h) ?t
     val L2 = filter (fn b => b >= h) ?t
 in qsort(L1,h::future qsort(L2,rest)) end;

fun quicksort(L) = qsort(L,nil);
```

Qsort Complexity

Sequential Partition
Parallel calls



Quicksort with Futures



Depth = O(n)

Work = O(n log n)

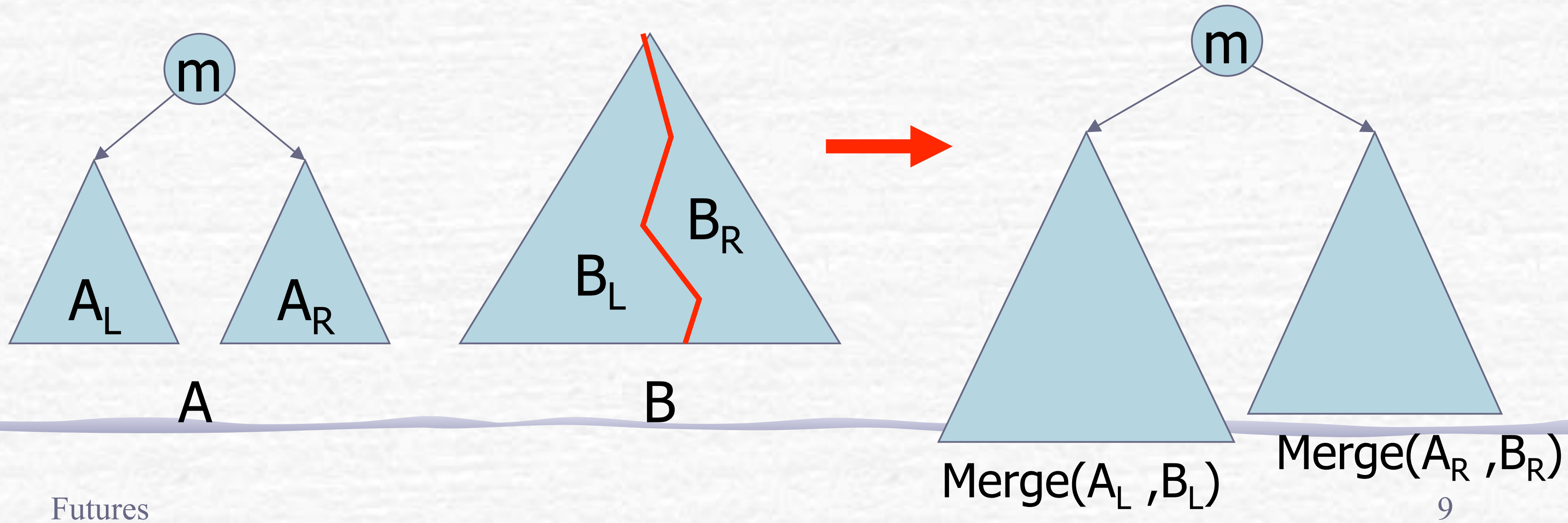
Still not a very good parallel algorithm

Merging

```
Merge(A,B) =
  let
    Node(A_L, m, A_R) = A
    (B_L ,B_R) = split(B, m)
  in
    Node(Merge(A_L,B_L), m, Merge(A_R,B_R))
```

Depth = $O(\log^2 n)$
Work = $O(n)$

Merge in parallel



Merging with Futures

```
Merge(A,B) =
  let
    Node(A_L, m, A_R) = A
    (B_L ,B_R) = futureSplit(B, m)
  in
    Node(Merge(A_L,B_L), m, Merge(A_R,B_R))
```

Depth = O(log n)
Work = O(n)