CS 251 Spring 2020
Principles of Programming Languages
Ben Wood

WELLESLEY

Parallelism

(and Concurrency)

Parallelism and Concurrency in 251

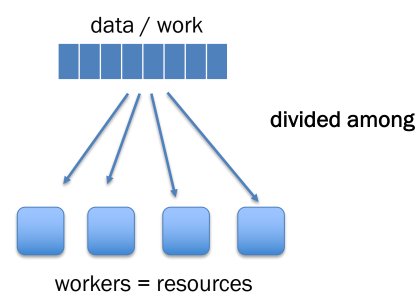
- Goal: encounter
  - essence, key concerns
  - non-sequential thinking
  - some high-level models
  - some mid-to-high-level mechanisms
- Non-goals:
  - performance engineering / measurement
  - deep programming proficiency
  - exhaustive survey of models and mechanisms

Eliminate 1 big assumption:

~~Evaluation happens~~
~~as a sequence of ordered steps.~~

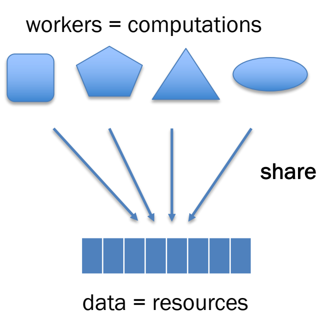
Parallelism

Use more resources
to complete work faster.



Concurrency

Coordinate access
to shared resources.

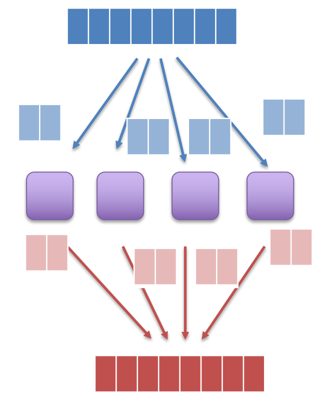


Both can be expressed using a variety of primitives.

Parallelism via Manticore

- Extends SML with language features for parallelism/concurrency.
- Mix research vehicle / established models.
- Parallelism patterns:
  - data parallelism:
    - parallel arrays
    - parallel tuples
  - task parallelism:
    - parallel bindings
    - parallel case expressions
- Unifying model:
  - futures / tasks
- Mechanism:
  - work-stealing

Data parallelism



Parallel arrays: `'a parray`

`[| e1, e2, …, en |]`	literal parray
`[| elo to ehi by estep |]`	integer ranges
`[| e	x in elems |]`	parallel mapping comprehensions
`[| e	x in elems where pred |]`	parallel filtering comprehensions

Parallel array comprehensions

`[| e1 | x in e2 |]`

Evaluation rule:

1. Under the current environment, ***E,*** evaluate ***e2*** to a parray ***v2***.
2. For each element ***vi*** in ***v2***, *with no constraint on relative timing order*:
   1. Create new environment ***Ei = x↦vi, E***.
   2. Under environment ***Ei***, evaluate ***e1*** to a value ***vi'***
3. The result is **`[| v1', v2', …, vn' |]`**

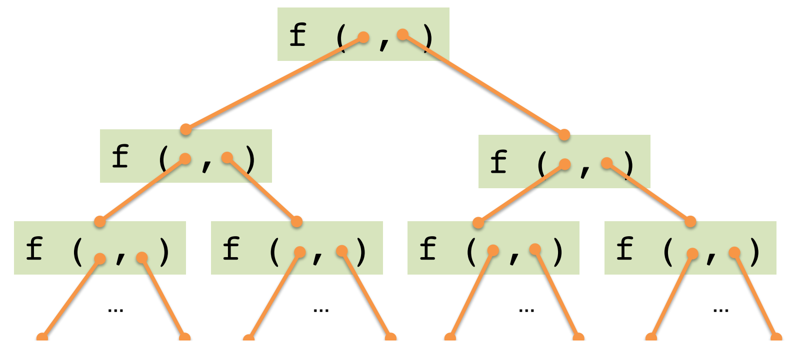
Parallel map / filter

```
fun mapP f xs =
      [| f x | x in xs |]

: ('a -> 'b) -> 'a parray -> 'b parray


fun filterP p xs =
      [| x | x in xs where p x |]

: ('a -> bool) -> 'a parray -> 'a parray
```

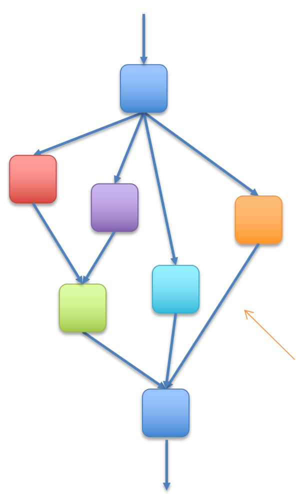

Parallel reduce

sibling of foldl/foldr
combiner function, `f`, must be ***associative***

```
fun reduceP f init xs = …

: (('a * 'a) -> 'a) -> 'a -> 'a parray -> 'a
```



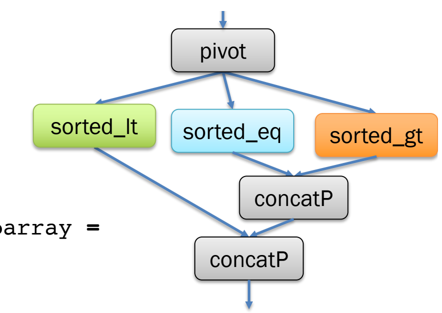
Task parallelism



parallelize application of different operations within larger computation

some ordering/interdependence controlled explicitly

Parallel bindings




```
fun qsortP (a: int parray) : int parray =
    if lengthP a <= 1
    then a
    else
        let
            val pivot = a ! 0  (* parray indexing *)
            pval sorted_lt =
                    qsortP (filterP (fn x => x < pivot) a)
            pval sorted_eq =
                    filterP (fn x => x = pivot) a
            pval sorted_gt =
                    qsortP (filterP (fn x => x > pivot) a)
        in
            concatP (sorted_lt, concatP (sorted_eq, sorted_gt))
        end
```

Start evaluating in parallel but don't wait until needed.

Wait until results are ready before using them.

Parallel cases

```
datatype 'a bintree = Empty
                    | Node of 'a * 'a bintree * 'a bintree

fun find_any t e =
    case t of
        Empty => NONE
      | Node (elem, left, right) =>
        if e = elem then SOME t
        else
            pcase find_any left e & find_any right e of

                SOME tree & ? => SOME tree
              | ? & SOME tree => SOME tree

              | NONE & NONE => NONE
```

Evaluate these in parallel.

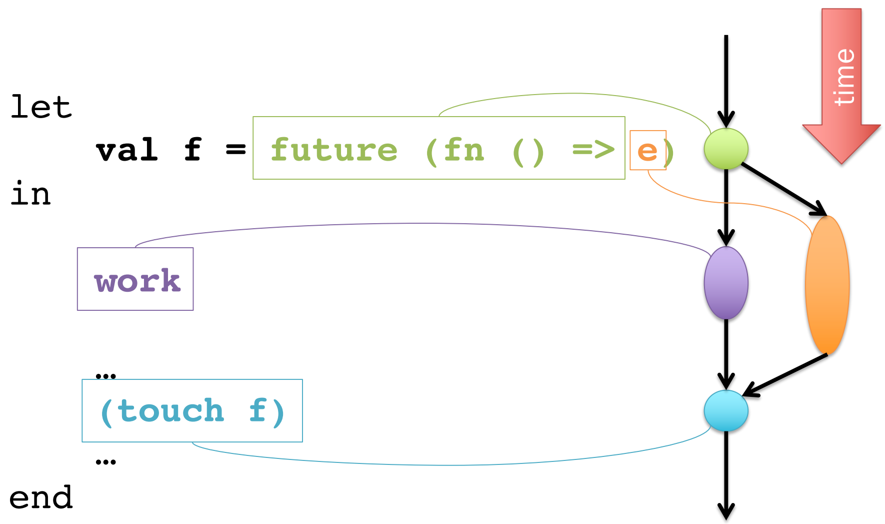
If one finishes with SOME, return it without waiting for the other.

If both finish with NONE, return NONE.

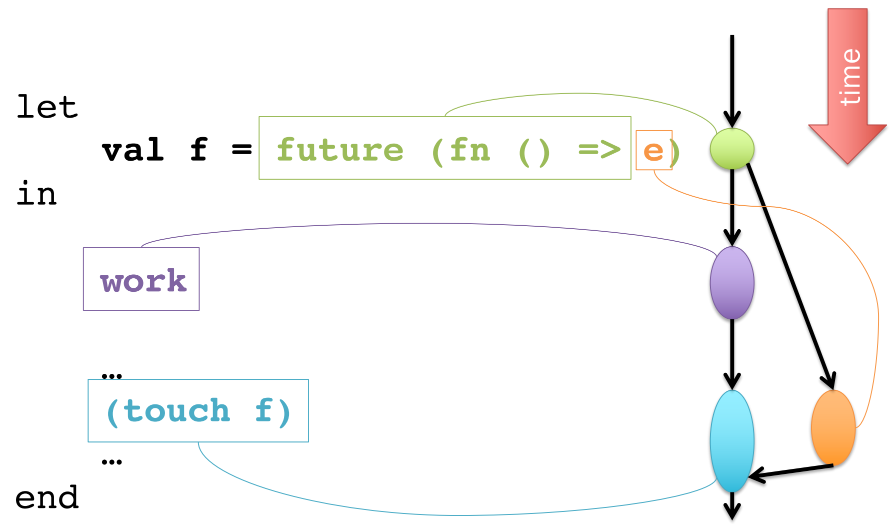
Futures: unifying model for Manticore parallel features

```
signature FUTURE =
sig
  type 'a future

  (* Produce a future for a thunk.
     Like Promise.delay. *)
  val future : (unit -> 'a) -> 'a future

  (* Wait for the future to complete and return the result.
     Like Promise.force. *)
  val touch : 'a future -> 'a

  (* More advanced features. *)
  datatype 'a result = VAL of 'a | EXN of exn

  (* Check if the future is complete and get result if so. *)
  val poll : 'a future -> 'a result option

  (* Stop work on a future that won't be needed. *)
  val cancel : 'a future -> unit
end
```


Futures: timeline visualization 1



Futures: timeline visualization 2



`pval` as future sugar

```
let pval x = e
in  … x …   end
```

```
let val x = future (fn () => e)
in  … (touch x) …  end
```

*a bit more: implicitly cancel an untouched future once it becomes clear it won't be touched.

Parray ops as futures: rough idea 1

Suppose we represent parrays as lists* of elements:

```
[| f x | x in xs |]
```

```
map touch
    (map (fn x =>
              future (fn () => f x))
     xs)
```

*actual implementation uses a more sophisticated data structure

Parray ops as futures: rough idea 2

Suppose we represent parrays as lists* of element futures:

```
[| f x | x in xs |]
```

```
map (fn x => future
         (fn () => f (touch x)))
    xs
```

Key semantic difference 1 vs 2?

*actual implementation uses a more sophisticated data structure

Odds and ends

- `pcase`: not just future sugar
  - *Choice* is a distinct primitive* not offered by futures alone.
- Where do execution resources from futures come from? How are they managed?
- Tasks vs futures:
  - Analogy: function calls vs. `val` bindings.
- Forward to concurrency and events…

*at least when implemented well.