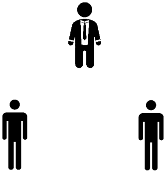
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Data-Parallel Programming

Parallel Programming and Data Analysis

Aleksandar Prokopec

Startup



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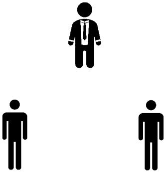

Everybody has to work. Work tasks are diverse.

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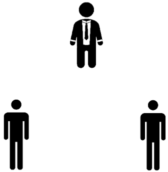
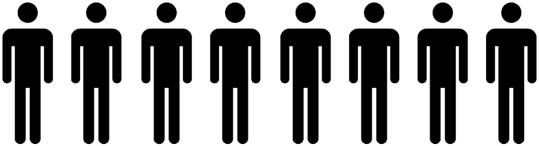


```
def startup[A, B, C](a: =>A, b: =>B, c: =>C): (A, B, C) = {
  val taskB = task { b }
  val taskC = task { c }
  (a, taskB.join(), taskC.join())
}
```

Factory



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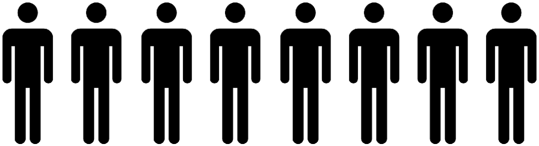

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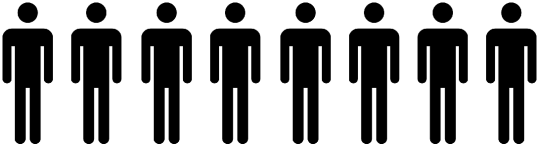

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How can we express parallelism here?

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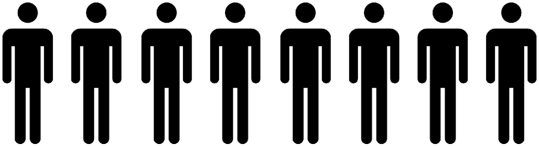

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def factory[A, B](items: Seq[A])
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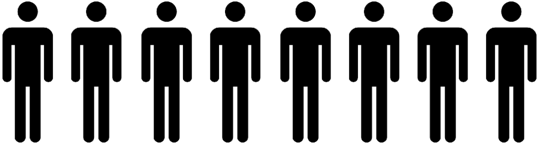

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How can we express parallelism here?

```
def factory[A, B](items: Seq[A])(f: A => B): Seq[B]
```

Data-Parallelism

Previously, we learned about task-parallel programming.

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Next, we learn about the data-parallel programming.

> *A form of parallelization that distributes data across computing nodes.*

Data-Parallel Programming Model

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def initializeArray(xs: Array[Int])(value: Int): Unit = {
  for (i <- (0 until xs.length).par) {

  }
}
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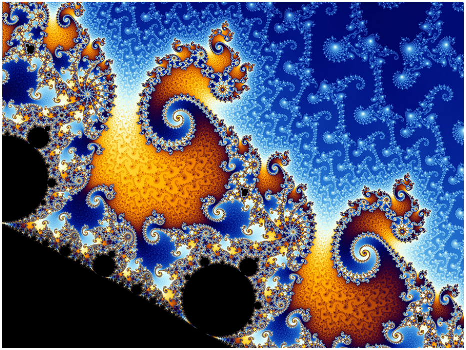
The parallel `for` loop is not very functional – it can only affect the program through side-effects.

As long as iterations of the parallel loop write to separate memory locations, the program is correct.

Example: Mandelbrot Set

Although simple, parallel `for` loop allows writing interesting programs.



Render a set of complex numbers in the plane for which the sequence $z_{n+1} = z_n^2 + c$ does not approach infinity.

Example: Mandelbrot Set

We approximate the definition of the Mandelbrot set – as long as the absolute value of z_n is less than 2, we compute z_{n+1} until we do `maxIterations`.

```scala
private def computePixel(xc: Double, yc: Double, maxIterations: Int): Int = {
  var i = 0
  var x, y = 0.0
  while (x * x + y * y < 4 && i < maxIterations) {
    val xt = x * x - y * y + xc
    val yt = 2 * x * y + yc
    x = xt; y = yt
    i += 1
  }
  color(i)
}
```

Example: Mandelbrot Set (Data-Parallel)

How do we render the set using data-parallel programming?

```
def render(): Unit = {
  for (idx <- 0 until image.length) {
    val (xc, yc) = coordinatesFor(idx)
    image(idx) = computePixel(xc, yc, maxIterations)
  }
}
def parRender(): Unit = {
  for (idx <- (0 until image.length).par) {
    val (xc, yc) = coordinatesFor(idx)
    image(idx) = computePixel(xc, yc, maxIterations)
  }
}
```

Rendering the Mandelbrot Set: Demo

Time for a demo!

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Summary:

- task-parallel implementation – the slowest.
- data-parallel implementation – about $2\times$ faster.

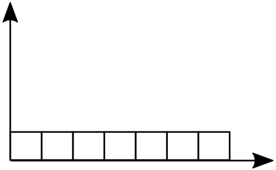
Workload

Different data-parallel programs have different workloads.

Workload is a function that maps each input element to the amount of work required to process it.

Uniform Workload

Defined by a constant function: $w(i) = const$



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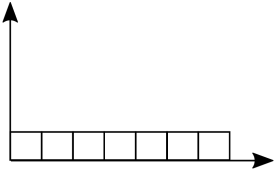
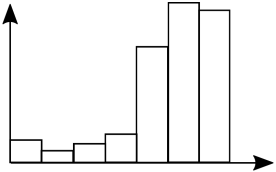


Easy to parallelize.

Irregular Workload

Defined by an arbitrary function: $w(i) = f(i)$



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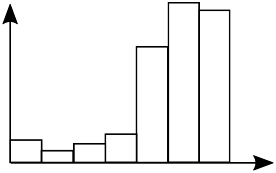

In the Mandelbrot case: $w(i) = \#\mathit{iterations}$

The workload depends on the problem instance.

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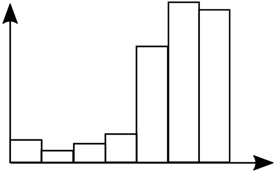

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The workload depends on the problem instance.

Goal of the *data-parallel scheduler*: efficiently balance the workload across processors without any knowledge about the $w(i)$.