PARALLEL PROGRAMMING IN GO FOR PERFORMANCE WITH THE PARGO LIBRARY

PASCAL COSTANZA

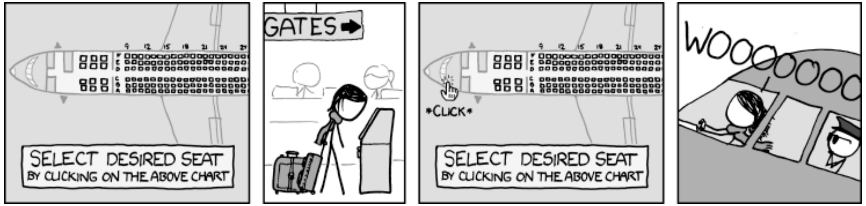
WHAT IS PARGO?

- Pargo is a library for parallel programming in Go at imec's ExaScience Lab:
  - based on our experiences with parallel programming in C++, Common Lisp, and Java
  - released under a BSD-style open source license at https://github.com/exascience/pargo
- Pargo supports numerous common parallel programming patterns:
  - Divide-and-conquer task-based parallelism
  - Parallel ranges, parallel reduction, parallel Boolean functions
  - Speculative parallelism
  - Parallel Quicksort and Mergesort
  - Parallel hash table
  - Parallel pipelines inspired by Java Parallel Streams introduced in JDK 8
    - including support for contexts, cancellation, and Go-style error handling

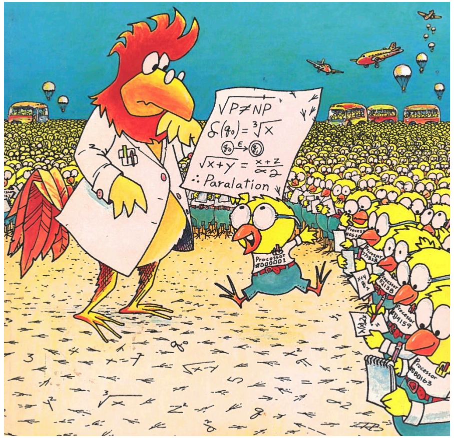
CONCURRENCY VS. PARALLELISM

- Concurrency is part of the problem domain.
- Needs solution even without multicore/node.
- Go is really good at this!

- Parallelism is part of the solution domain.
- Only needed for performance.
- Pargo is really good at this! ;)



https://xkcd.com/726/



Gary W. Sabot, The Paralation Model, The MIT Press, 1988

PARALLEL PROGRAMMING: AN EXAMPLE

```go
func sum(numbers []float64) float64 {
	var sum float64
	for _, number := range numbers {
		sum += number
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PARALLEL PROGRAMMING: AN EXAMPLE

```go
func sum(numbers []float64) float64 {
	if len(numbers) < threshold {
		var sum float64
		for _, number := range numbers {
			sum += number
		}
		return sum
	}
	half := len(numbers) / 2
	var wg sync.WaitGroup
	wg.Add( delta: 1)
	var left float64
	go func() {
		defer wg.Done()
		left = sum(numbers[:half])
	}()
	right := sum(numbers[half:])
	wg.Wait()
	return left + right
}
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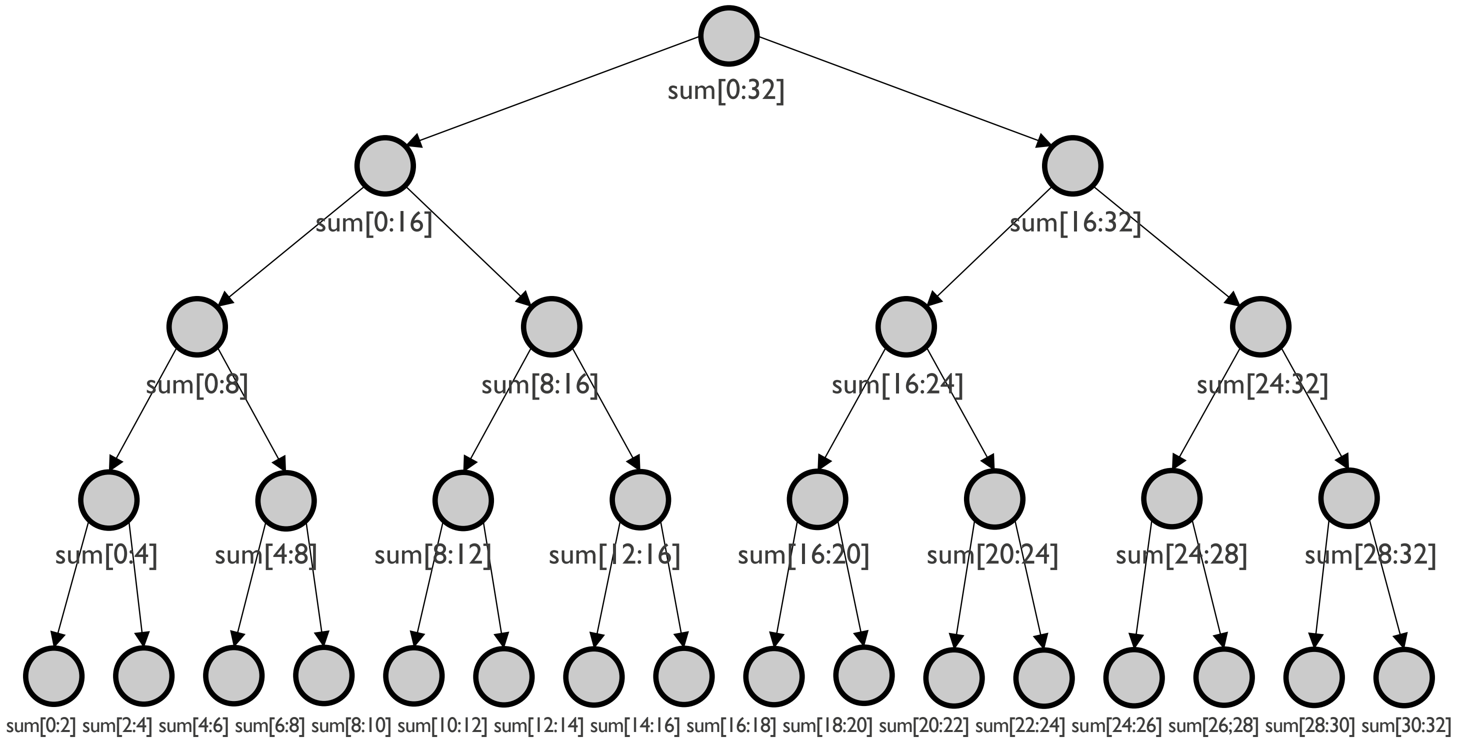
DIVIDE-AND-CONQUER TASK-BASED PARALLELISM



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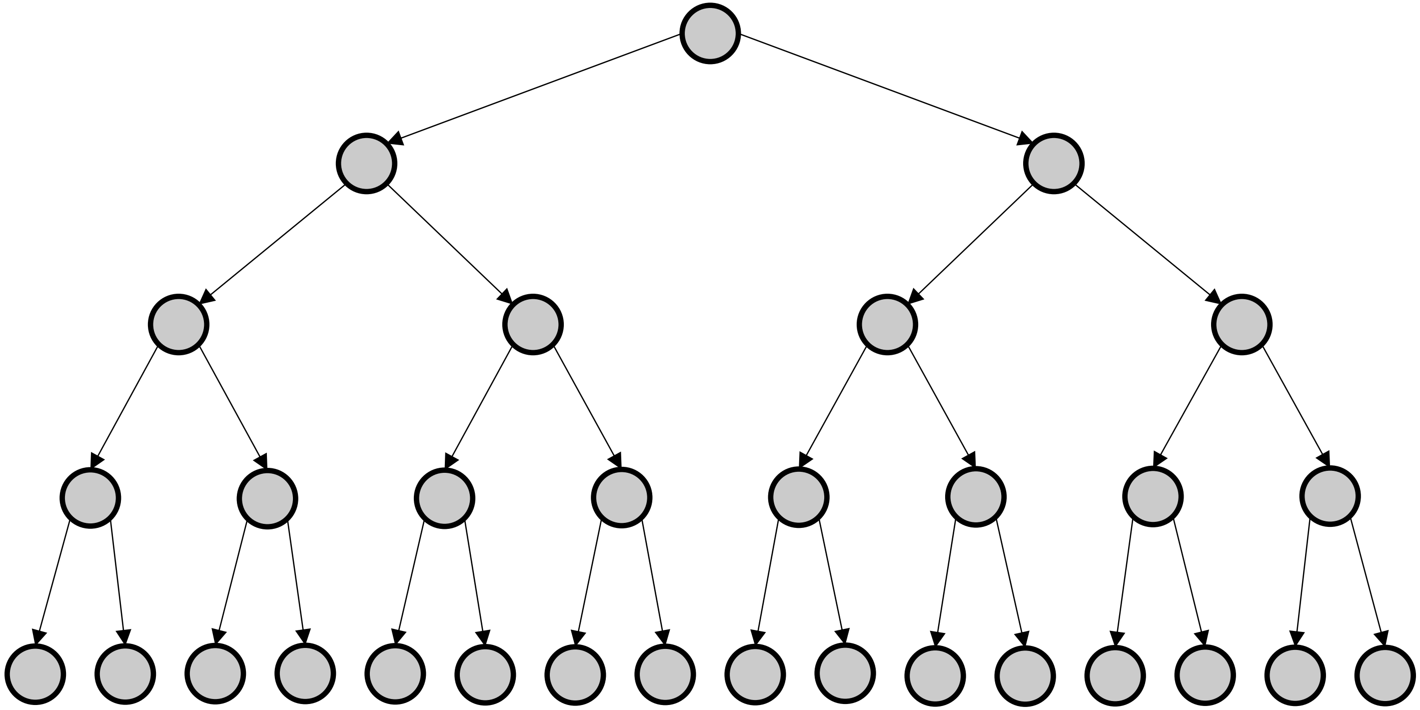
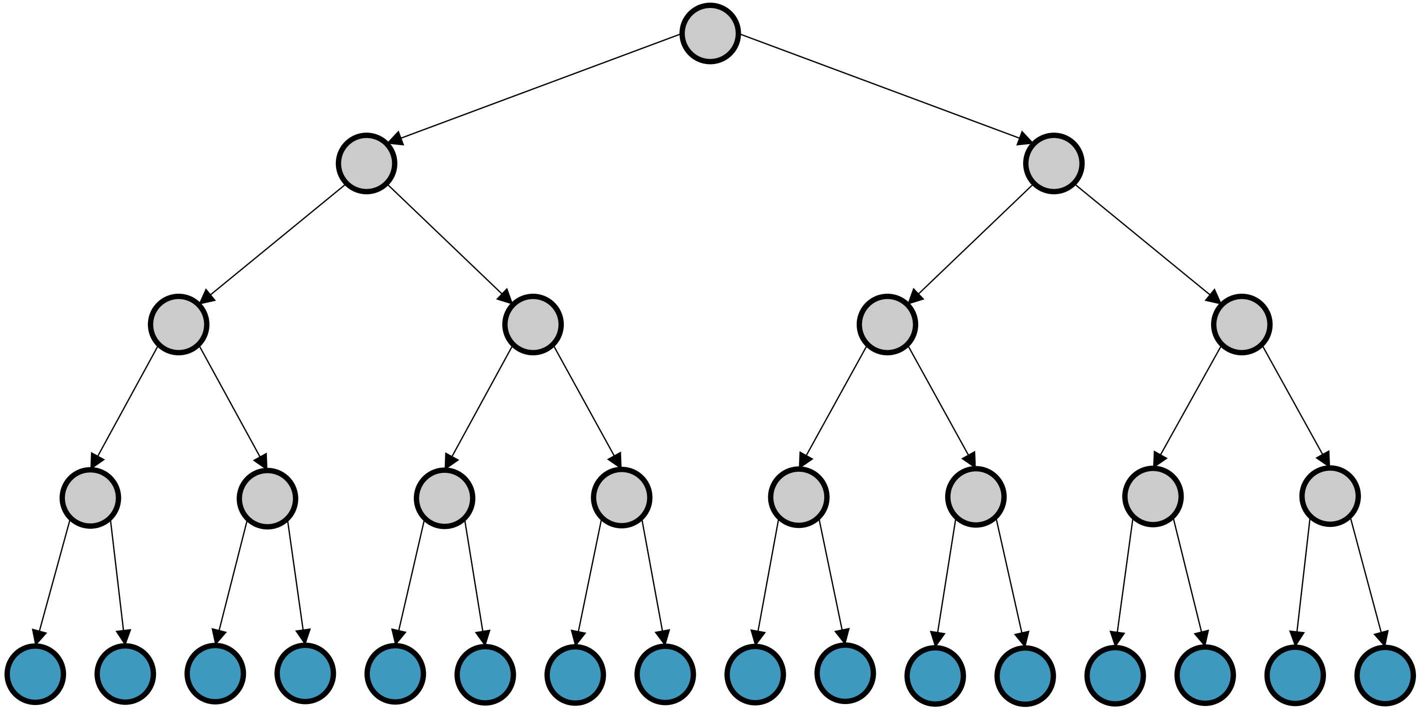


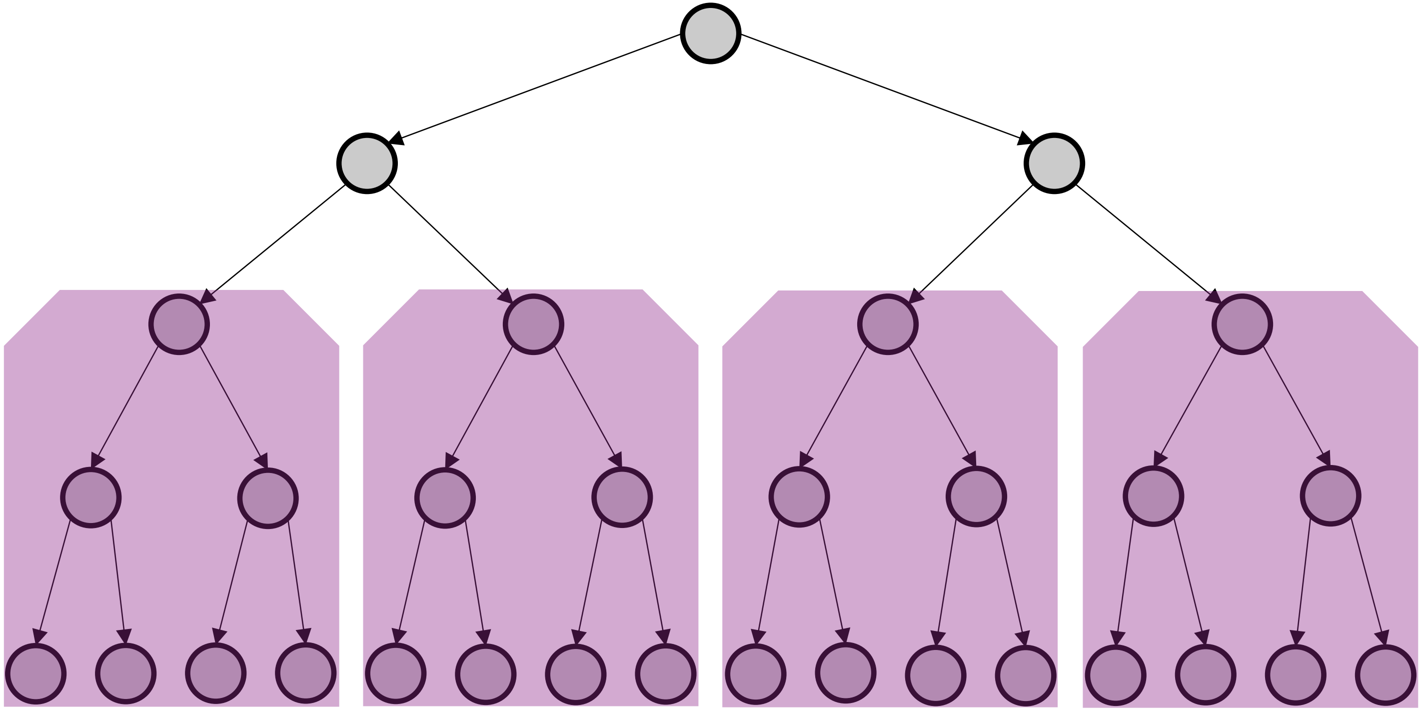
DIVIDE-AND-CONQUER TASK-BASED PARALLELISM

WITH 16 CORES



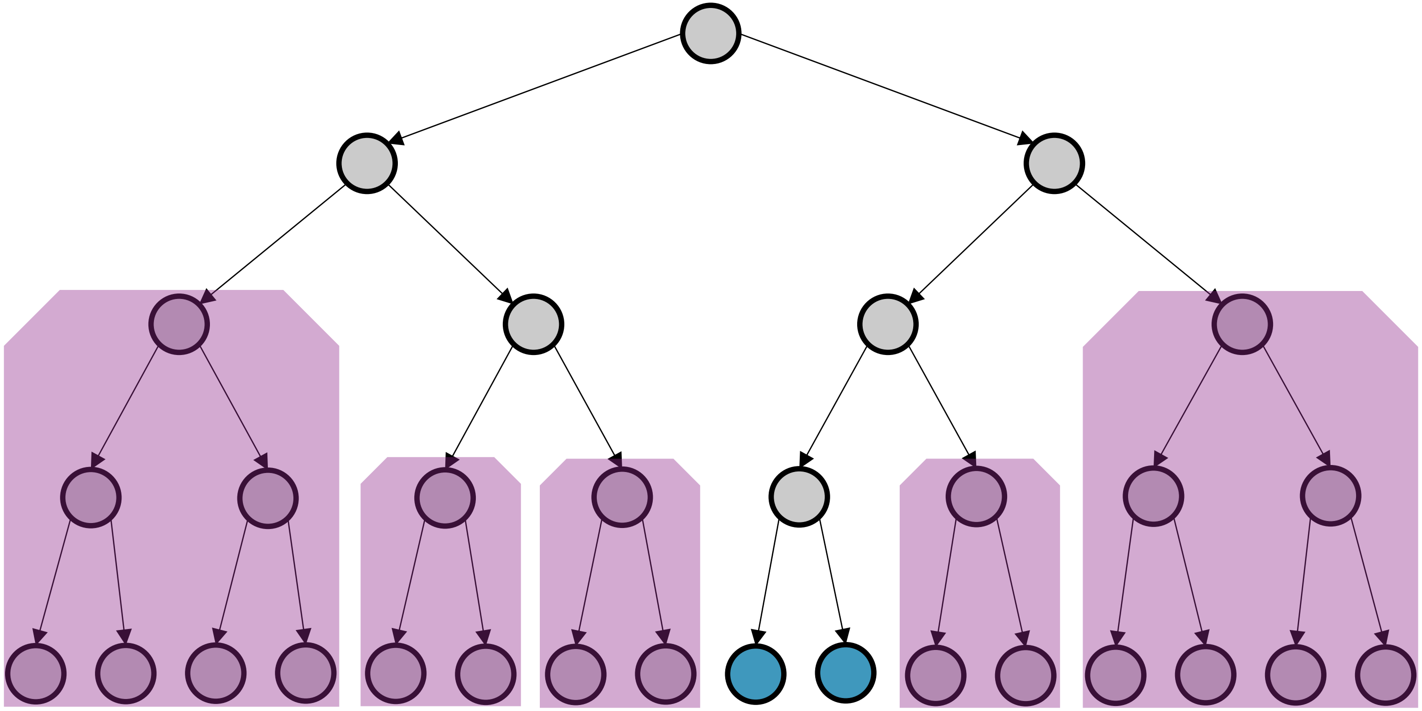
DIVIDE-AND-CONQUER TASK-BASED PARALLELISM

WITH 4 CORES



DIVIDE-AND-CONQUER TASK-BASED PARALLELISM

WITH LOAD IMBALANCE



DIVIDE-AND-CONQUER TASK-BASED PARALLELISM

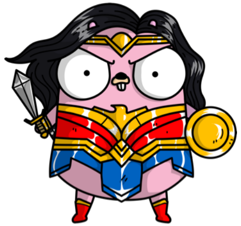
- Task-based parallelism allows flexible distribution of work over CPU cores.
- Distributing work evenly over cores is often not optimal, because of load imbalance.

DIVIDE-AND-CONQUER TASK-BASED PARALLELISM

- Task-based parallelism allows flexible distribution of work over CPU cores.
- …but how are tasks *actually* scheduled over the cores?

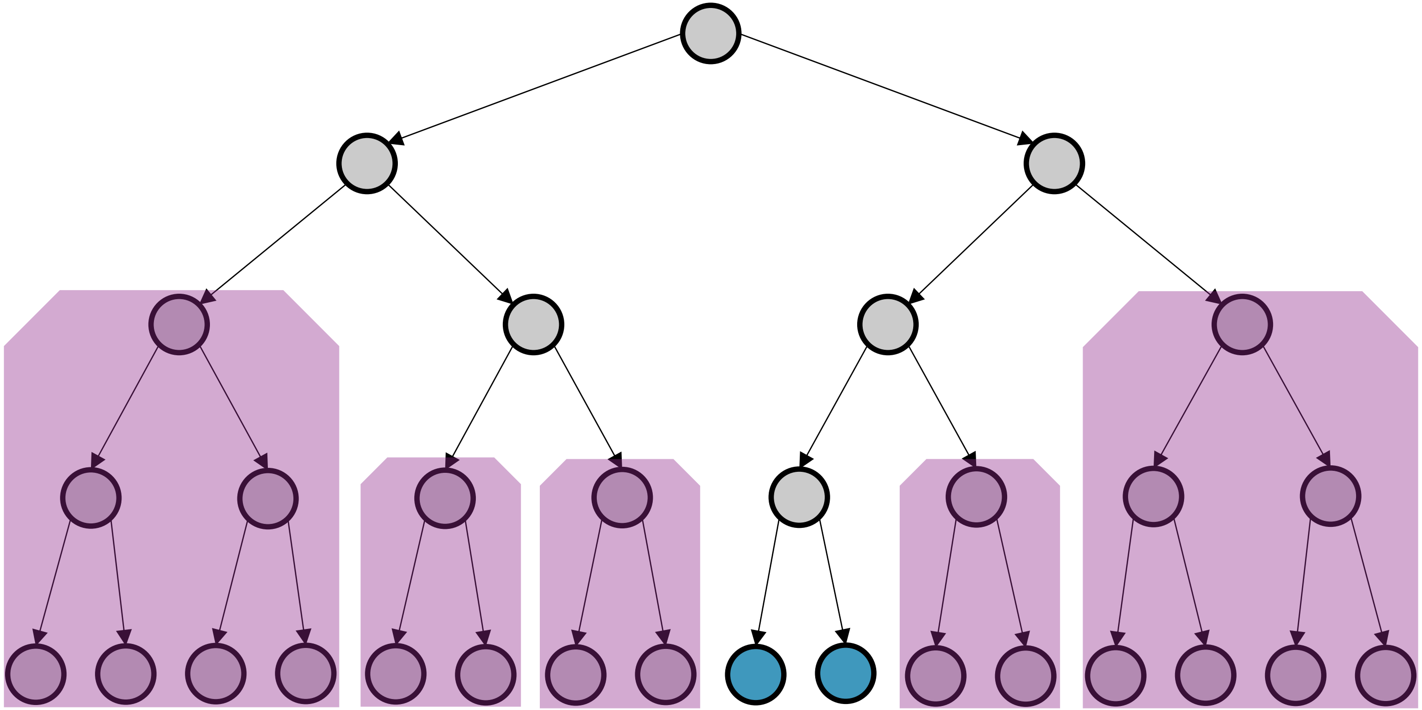
WORK STEALING

- Work stealing is known to be optimal both in theory and practice
  - Blumofe, Leiserson: Scheduling Multithreaded Computations by Work Stealing, Journal of the ACM, 1999
  - Frigo, Leiserson, Randall: The Implementation of the Cilk-5 Multithreaded Language, PLDI'98
- Successfully implemented in many languages and libraries:
  - Cilk for C; Threading Building Blocks for C++; Java fork/join; …
  - …and Go



Wonder Gopher by Ashley McNamara,
https://github.com/ashleymcnamara/gophers

WORK STEALING FINDS OPTIMAL DISTRIBUTION ON THE FLY



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	wg.Wait()
	return left + right
}
```

THE EXAMPLE PROGRAM IN PARGO

```go
import "github.com/exascience/pargo/parallel"

func sum(numbers []float64) float64 {
	return parallel.RangeReduceFloat64( low: 0, len(numbers),  n: 0,
		func (low, high int) float64 {
			var sum float64
			for i := low; i < high; i++ {
				sum += numbers[i]
			}
			return sum
		},
		func (left, right float64) float64 {
			return left + right
		},
	)
}
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```

…AND LOTS OF OTHER PARALLEL PROGRAMMING PATTERNS

- Parallel Do
- Parallel range
- Parallel reduction over int, float64, string, interface{}
- Parallel range reduction over int, float64, string, interface{}
- Parallel And, Or, RangeAnd, RangeOr
- Speculative variants of many of the above functions
- Sequential variants for debugging
- Parallel Quicksort and merge sort
- A parallel hash table (similar to Go’s sync.Map)
- …and parallel pipelines.

CONCURRENT PIPELINES IN GO

```go
func gen(numbers []int) <- chan int {
    out := make(chan int)
    go func() {
        for _, number := range numbers {
            out <- number
        }
        close(out)
    }()
    return out
}

func square(in <-chan int) <-chan int {
    out := make(chan int)
    go func() {
        for number := range in {
            out <- number * number
        }
        close(out)
    }()
    return out
}

func main() {
    for n := range square(gen([]int{2, 3})) {
        fmt.Println(n)
    }
}
```

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PARALLEL PIPELINES USING PARGO

```go
func main() {
	var p pipeline.Pipeline
	p.Source([]int{2, 3})
	p.Add(
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			return numbers
		})),
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			numbers := data.([]int)
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```

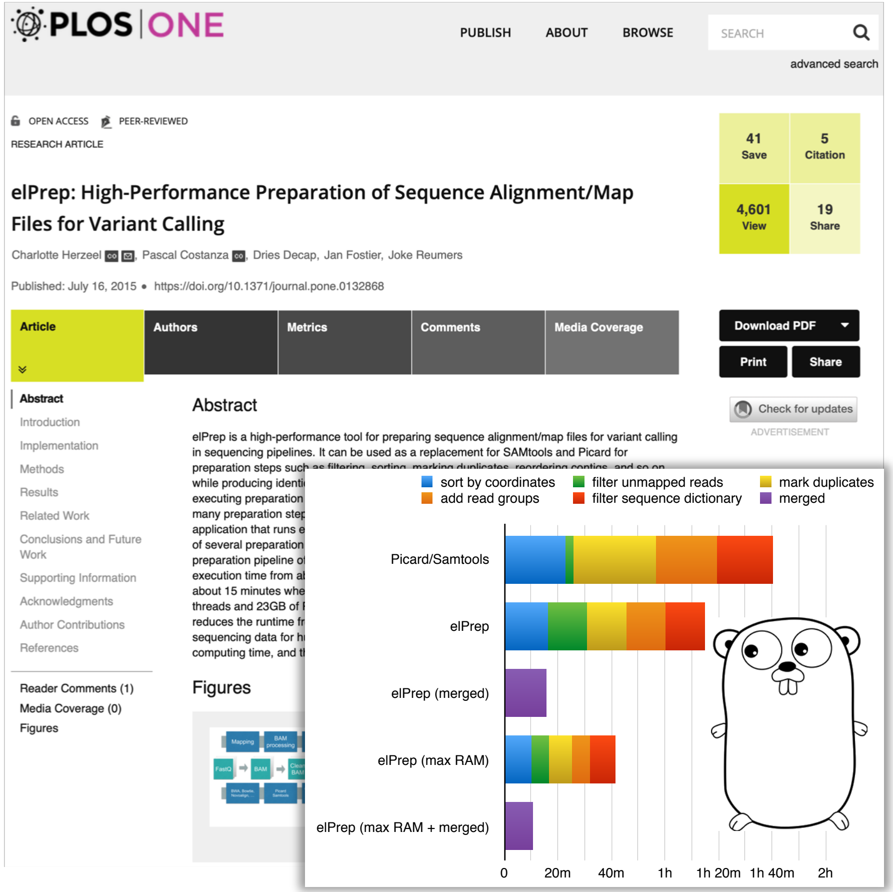
PARALLEL PIPELINES IN PARGO

- Predefined pipeline sources for arrays, slices, strings, channels, and bufio.Scanner.
- Support for user-defined sources through the pipeline.Source interface.
- Support for several kinds of nodes (stages):
  - Sequential, ordered, parallel
  - Strictly ordered, limited parallel
  - Skip and Limit nodes
- Support for several kinds of filters:
  - Generic receive and finalize
  - Boolean filters: Every, Some, NotEvery, NotAny
  - Counting filter
  - Slice filter
- Support for contexts, including cancellation
- Support for error handling, including cancellation on error
- Support for fine-tuning of batch sizes

ELPREP: A HIGH-PERFORMANCE TOOL FOR SEQUENCING

- High-performance tool for preparing SAM files for variant calling.
- Multi-threaded application that runs entirely in RAM and merges multiple steps to avoid repeated file I/O.
- Can improve performance by a factor of up to x10 compared to standard tools.

- elPrep implemented in Go since version 3.0
  - https://github.com/exascience/elprep



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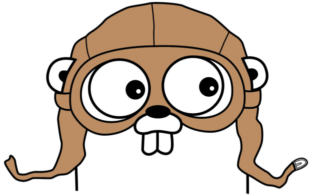
PARGO

- Pargo available at https://github.com/exascience/pargo
- Documentation: https://godoc.org/github.com/exascience/pargo
- More documentation: https://github.com/exascience/pargo/wiki
- elPrep: https://github.com/exascience/elprep



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