# Package foreach

PARALLEL PROGRAMMING IN R

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# What is foreach for?

- Developed by Rich Calaway and Steve Weston.
- Provides a new looping construct for repeated execution.
- Supports running loops in parallel.
- Unified interface for sequential and parallel processing.
- Greatly suited for embarrassingly parallel applications.

# foreach looping construct

`foreach(...) %do% ...`

```
library(foreach)
foreach(n = rep(5, 3)) %do% rnorm(n)
```

```
[[1]]
[1] -0.6264538  0.1836433 -0.8356286  1.5952808  0.3295078

[[2]]
[1] -0.8204684  0.4874291  0.7383247  0.5757814 -0.3053884

[[3]]
[1]  1.5117812  0.3898432 -0.6212406 -2.2146999  1.1249309
```

# Iteration variables

```
foreach(n = rep(5, 3), m = 10^(0:2)) %do% rnorm(n, mean = m)
```

```
[[1]]
[1] 0.3735462 1.1836433 0.1643714 2.5952808 1.3295078

[[2]]
[1]  9.179532 10.487429 10.738325 10.575781  9.694612

[[3]]
[1] 101.51178 100.38984  99.37876  97.78530 101.12493
```

# Combining results

```
foreach(n = rep(5, 3), .combine = rbind) %do% rnorm(n)
```

```
             [,1]      [,2]       [,3]       [,4]       [,5]
result.1 -0.6264538 0.1836433 -0.8356286  1.5952808  0.3295078
result.2 -0.8204684 0.4874291  0.7383247  0.5757814 -0.3053884
result.3  1.5117812 0.3898432 -0.6212406 -2.2146999  1.1249309
```

```
foreach(n = rep(5, 3), .combine = '+') %do% rnorm(n)
```

```
0.06485897  1.06091561 -0.71854449 -0.04363773  1.14905030
```

# List comprehension

```
foreach(x = sample(1:1000, 10), .combine = c) %:%
    when(x %% 3 == 0 || x %% 5 == 0) %do% x
```

```
372 906 201 894 940 657 625
```

# Let's practice!

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# foreach & parallel backends

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# Popular backends

- `doParallel` (`parallel`)
- `doFuture` (`future`)
- `doSEQ` (for consistent sequential interface)

# doParallel (Rich Calaway et al.) package

- Interface between `foreach` and `parallel`
- Must register via `registerDoParallel()` with cluster info
- Quick registration:

```
library(doParallel)
registerDoParallel(cores = 3)
```

- using *multicore* functionality for Unix-like systems (fork)
- using *snow* functionality for Windows systems

# doParallel (Rich Calaway et al.) package

- Register by passing a cluster object:

```
library(doParallel)
cl <- makeCluster(3)
registerDoParallel(cl)
```

- will use *snow* functionality

# Using doParallel

Sequential:

```
library(foreach)
foreach(n = rep(5, 3)) %do% rnorm(n)
```

Parallel:

```
library(doParallel)
cl <- makeCluster(3)
registerDoParallel(cl)
foreach(n = rep(5, 3)) %dopar% rnorm(n)
```

```
[[1]]
[1] -1.1671919 -0.0360007 -0.5972832  1.0380735 -0.05085

[[2]]
[1]  0.370006 -0.419358  0.131176  0.656627 -0.037162

[[3]]
[1]  0.987222 -1.169738  0.399277 -0.155607 -1.034571
```

# doFuture (Henrik Bengtsson) package

- On top of the `future` package
- How to **plan** the future:
  - sequential
  - cluster
  - multicore
  - multiprocess
- `future.batchtools` : run processes on HPC clusters (Torque, Slurm, SGE etc.)

# Using doFuture

```
library(doFuture)
registerDoFuture()
```

**Cluster plan:**

```
plan(cluster, workers = 3)
foreach(n = rep(5, 3)) %dopar% rnorm(n)
```

# Using doFuture

**Multicore plan:**

```
plan(multicore)
foreach(n = rep(5, 3)) %dopar% rnorm(n)
```

# Let's practice!

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# Packages future and future.apply

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# future package

- Developed by Henrik Bengtsson (now also funded by R Consortium)
- Uniform way to evaluate R expressions asynchronously
- Provides a unified API for sequential and parallel processing of R expressions
- Processing via a construct called `future`
- An abstraction for a value that may be available at some point in the future

## Example in plain R:

```
x <- mean(rnorm(n, 0, 1))
y <- mean(rnorm(n, 10, 5))
print(c(x, y))
```

## Via implicit futures:

```
x %<-% mean(rnorm(n, 0, 1))
y %<-% mean(rnorm(n, 10, 5))
print(c(x, y))
```

## Via explicit futures:

```
x <- future(mean(rnorm(n, 0, 1)))
y <- future(mean(rnorm(n, 10, 5)))
print(c(value(x), value(y)))
```

# Sequential and parallel futures

**Sequential:**

```
plan(sequential)
x %<-% mean(rnorm(n, 0, 1))
y %<-% mean(rnorm(n, 10, 5))
print(c(x, y))
```

**Parallel:**

```
plan(multicore)
x %<-% mean(rnorm(n, 0, 1))
y %<-% mean(rnorm(n, 10, 5))
print(c(x, y))
```

# future.apply package

- Developed by Henrik Bengtsson
- Provide parallel API for all the apply functions in base R using futures
- *Sibling* to `foreach`
- Functions: `future_lapply()`, `future_sapply()`, `future_apply()`, ...

# Example of future.apply

Using `lapply()`:

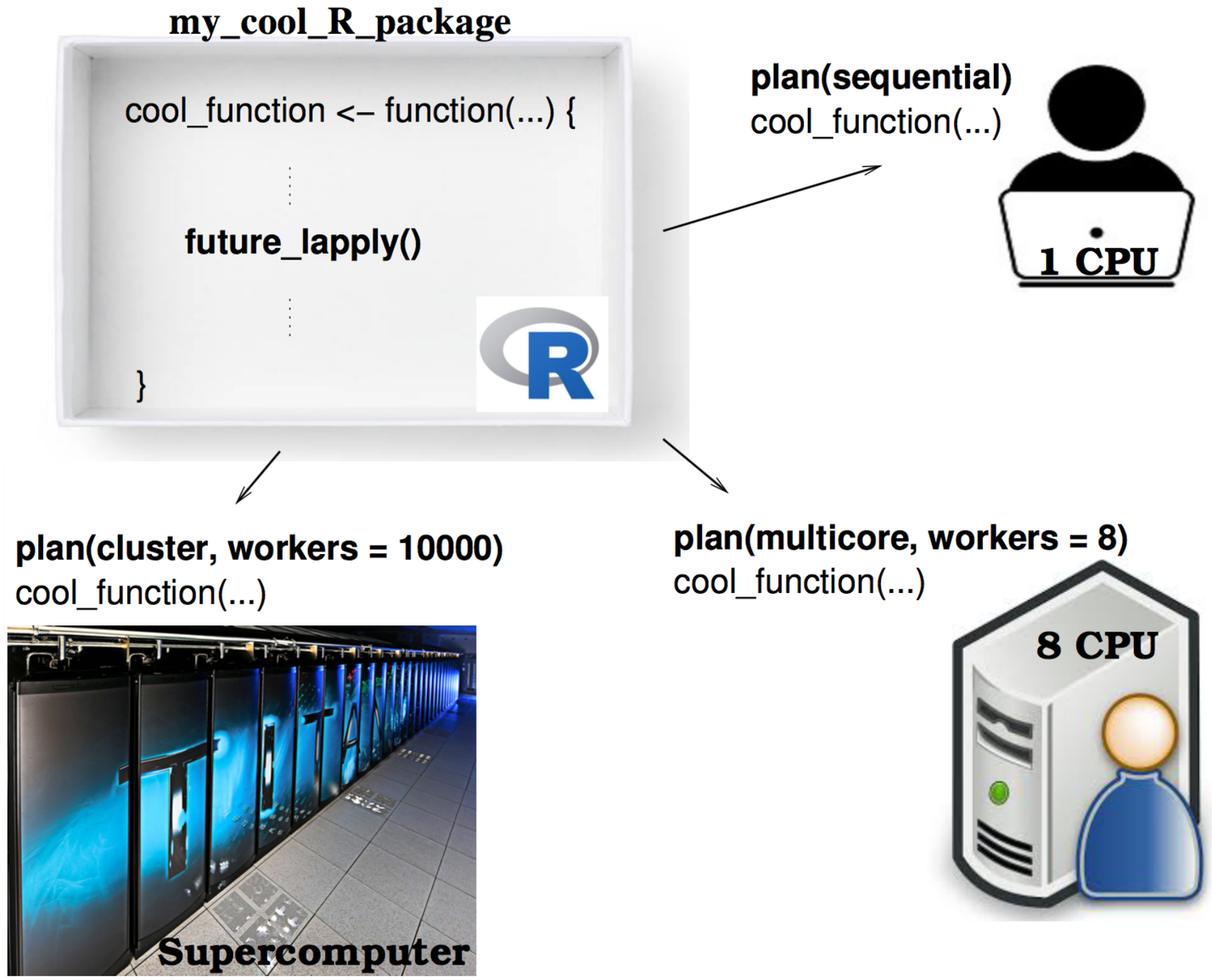
```
lapply(1:10, rnorm)
```

Using `future_lapply()` sequentially:

```
plan(sequential)
future_lapply(1:10, rnorm)
```

Using `future_lapply()` on a cluster:

```
plan(cluster, workers = 4)
future_lapply(1:10, rnorm)
```


my_cool_R_package
cool_function <- function(...) {
future_lapply()
}
plan(sequential)
cool_function(...)
1 CPU
plan(cluster, workers = 10000)
cool_function(...)
Supercomputer
plan(multicore, workers = 8)
cool_function(...)
8 CPU

# Let's practice!

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# Load balancing and scheduling

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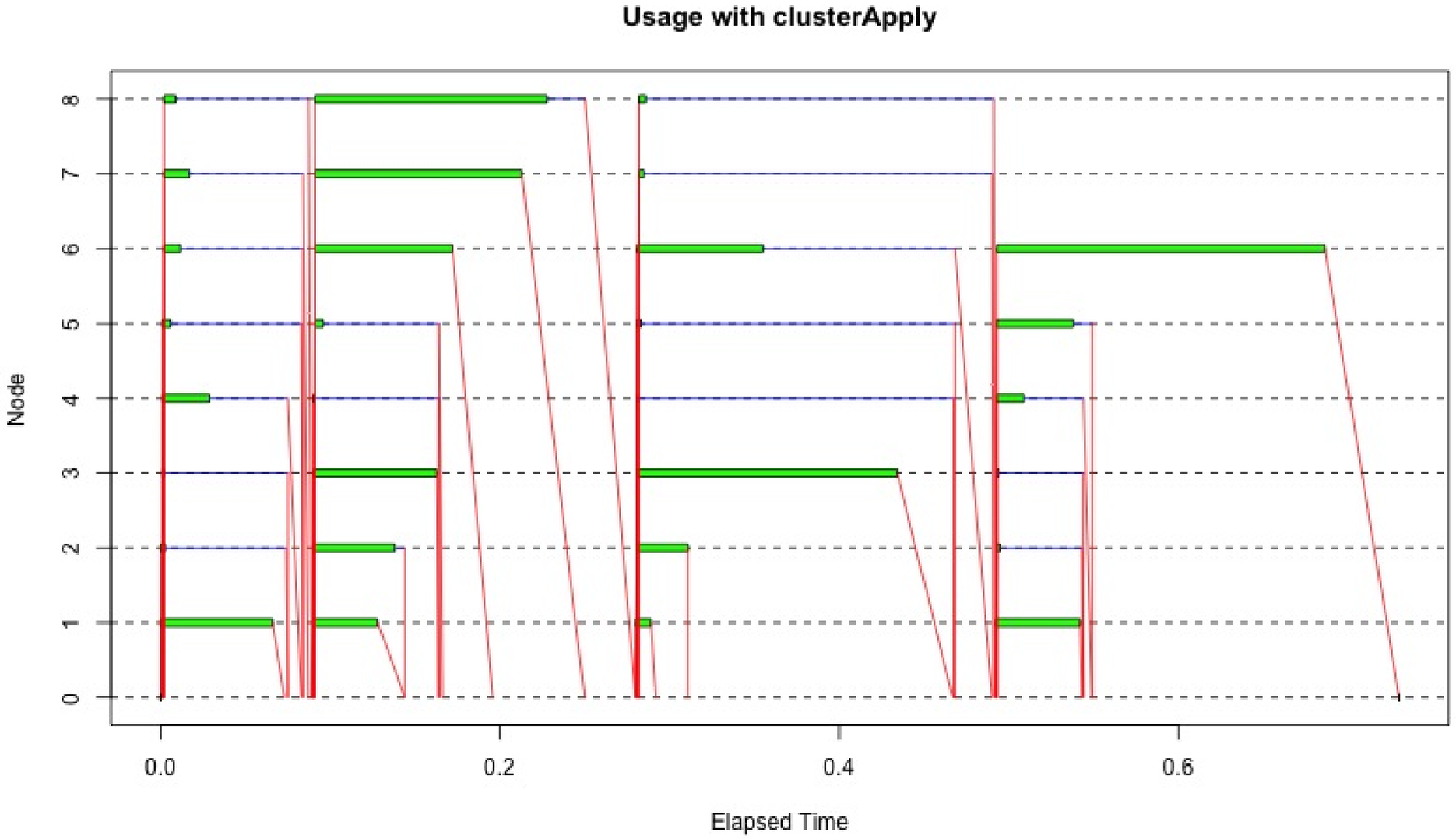
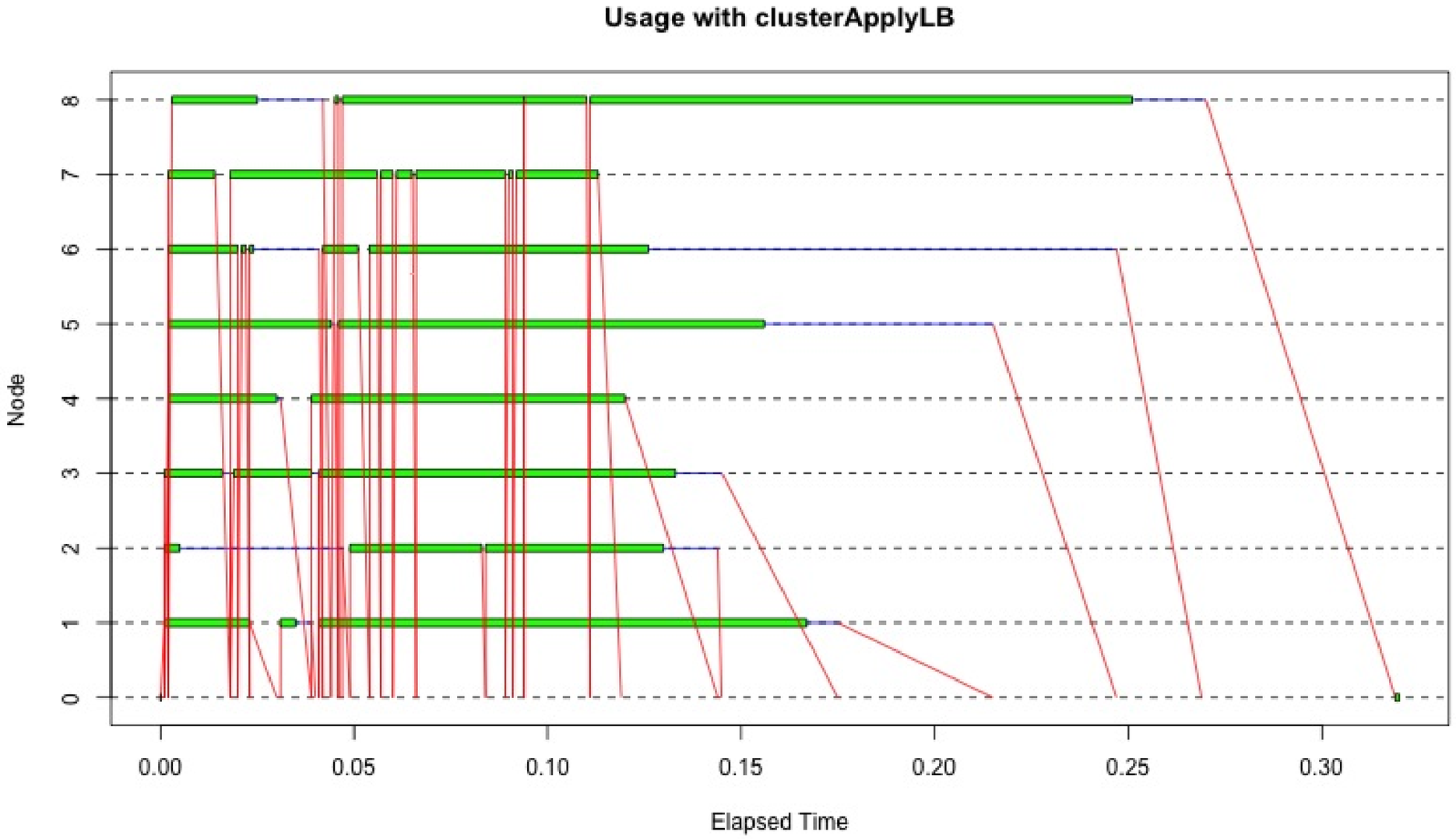
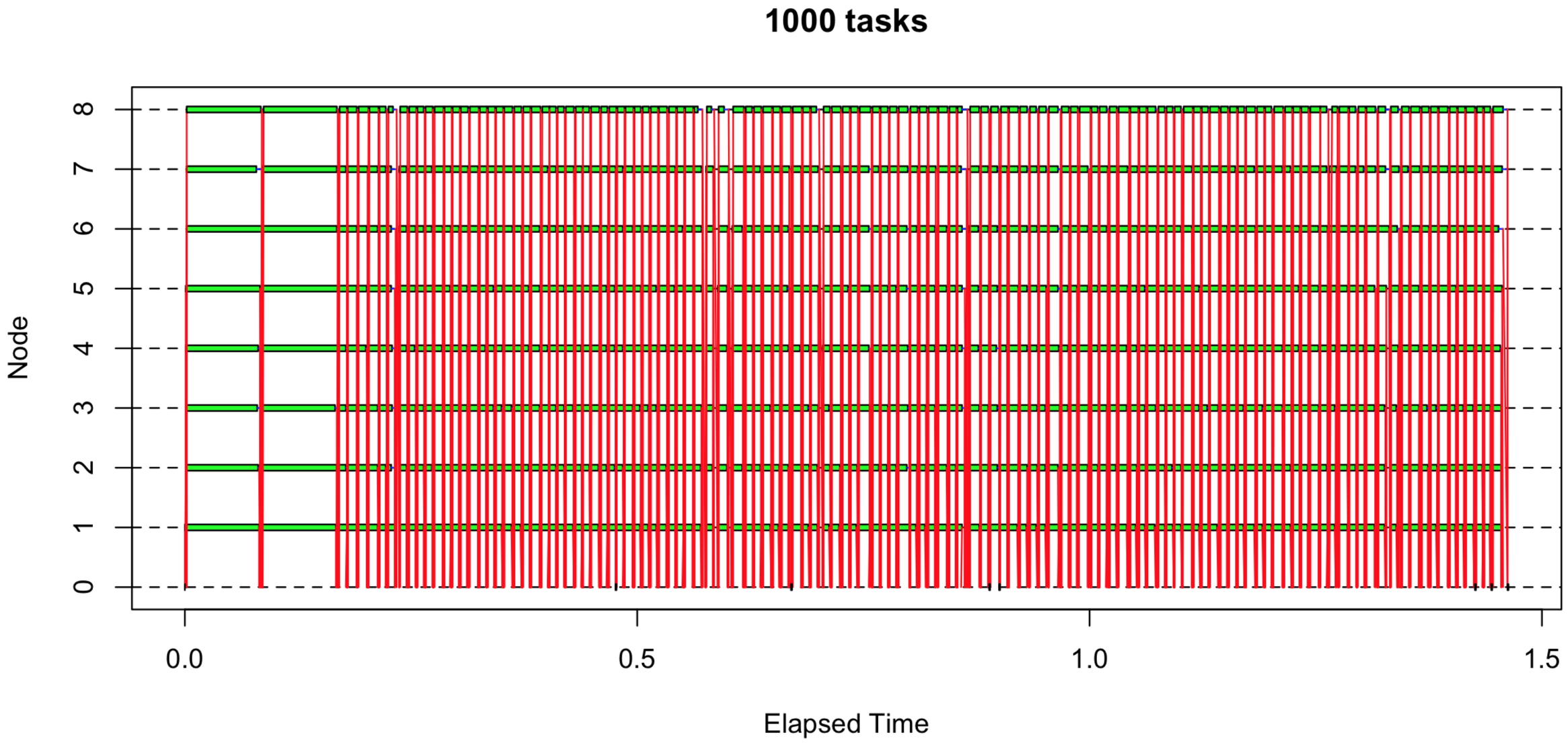
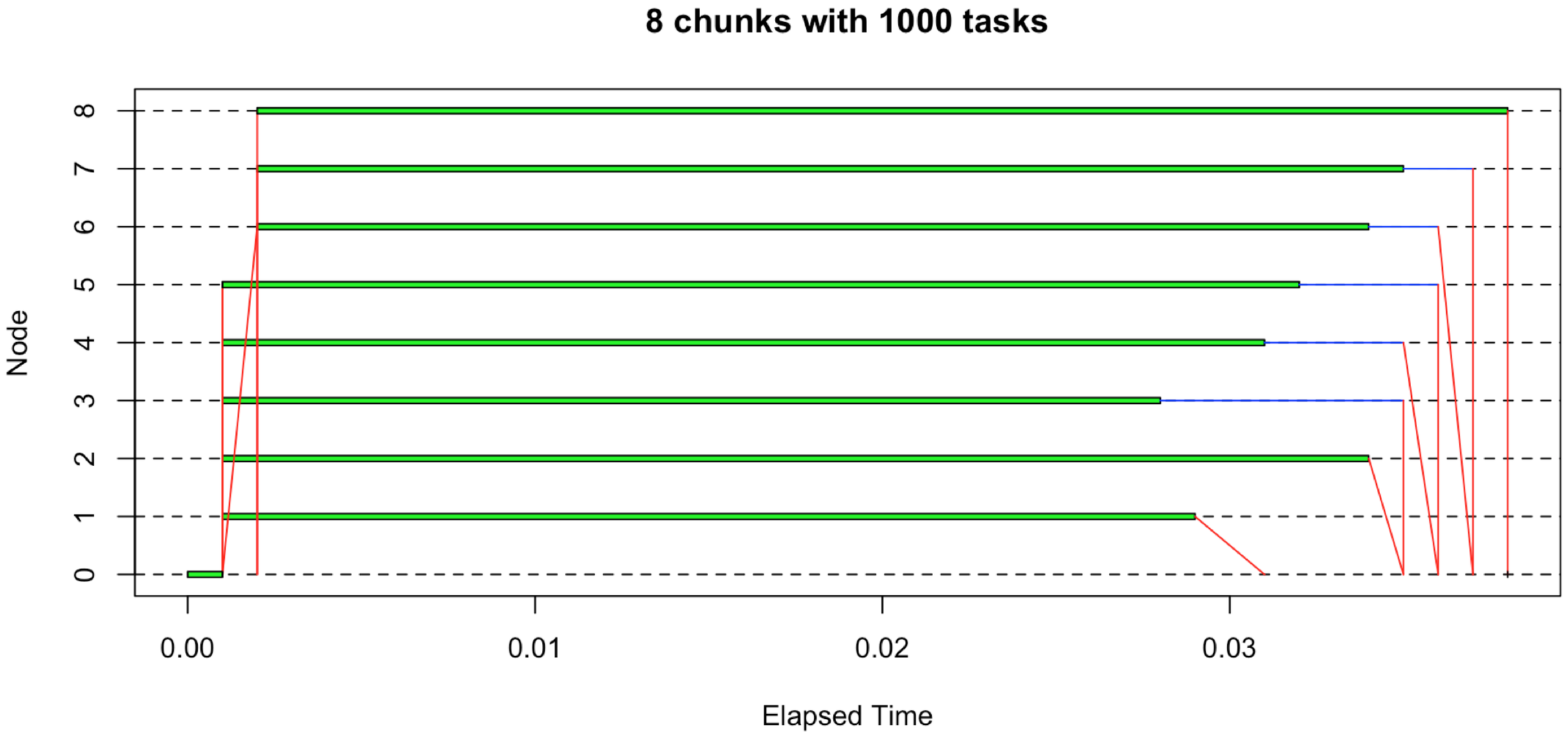

Usage with clusterApply
Node
0
1
2
3
4
5
6
7
8
0.0
0.2
0.4
0.6
Elapsed Time


Usage with clusterApplyLB
Node
0
1
2
3
4
5
6
7
8
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Elapsed Time


1000 tasks
Node
0
1
2
3
4
5
6
7
8
0.0
0.5
1.0
1.5
Elapsed Time


8 chunks with 1000 tasks
Node
0
1
2
3
4
5
6
7
8
0.00
0.01
0.02
0.03
Elapsed Time

Group 10 tasks into 2 chunks using the `parallel` package:

```
splitIndices(10, 2)
```

```
[[1]]
[1] 1 2 3 4 5

[[2]]
[1]  6  7  8  9 10
```

```
clusterApply(cl, x = splitIndices(10, 2), fun = sapply, "*", 100)
```

```
[[1]]
[1] 100 200 300 400 500

[[2]]
[1]  600  700  800  900 1000
```

Built into functions `parApply()` and friends (arg. `chunk.size` for R >= 3.5)

# How to chunk in foreach and future.apply?

For `foreach`, use functions from the `itertools` package, e.g.:

```
foreach(s = isplitVector(1:10, chunks = 2)) %dopar% sapply(s, "*", 100)
```

For `future.apply`, use argument `future.scheduling`, e.g.

- one chunk per worker (default):

```
future_sapply(1:10, `*`, 100, future.scheduling = 1)
```

- One chunk per task:

```
future_sapply(1:10, `*`, 100, future.scheduling = FALSE)
```

# Let's practice!

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