A Changepoints package for Julia

Jamie Fairbrother, Lawrence Bardwell, Kaylea Haynes

January 5, 2016

Why Julia? `julialang.org`

- Julia is a high-level, high-performance dynamic programming language for technical computing

Why Julia? `julialang.org`

- Julia is a high-level, high-performance dynamic programming language for technical computing
- Good performance, approaching that of statically-compiled languages like C

Why Julia? julialang.org

- Julia is a high-level, high-performance dynamic programming language for technical computing
- Good performance, approaching that of statically-compiled languages like C
- Multiple dispatch: providing ability to define function behavior across many combinations of argument types

Why Julia? `julialang.org`

- Julia is a high-level, high-performance dynamic programming language for technical computing
- Good performance, approaching that of statically-compiled languages like C
- Multiple dispatch: providing ability to define function behavior across many combinations of argument types
- Lisp-like macros and other metaprogramming facilities

Why Julia? `julialang.org`

- Julia is a high-level, high-performance dynamic programming language for technical computing
- Good performance, approaching that of statically-compiled languages like C
- Multiple dispatch: providing ability to define function behavior across many combinations of argument types
- Lisp-like macros and other metaprogramming facilities
- Advanced package management

Why Julia? `julialang.org`

- Julia is a high-level, high-performance dynamic programming language for technical computing
- Good performance, approaching that of statically-compiled languages like C
- Multiple dispatch: providing ability to define function behavior across many combinations of argument types
- Lisp-like macros and other metaprogramming facilities
- Advanced package management
- Call C functions directly: no wrappers or special APIs

Why Julia? `julialang.org`

- Julia is a high-level, high-performance dynamic programming language for technical computing
- Good performance, approaching that of statically-compiled languages like C
- Multiple dispatch: providing ability to define function behavior across many combinations of argument types
- Lisp-like macros and other metaprogramming facilities
- Advanced package management
- Call C functions directly: no wrappers or special APIs
- Efficient support for Unicode, including but not limited to UTF-8

Changepoints.jl Features

- Flexible macro for simulating time series with changepoints

Changepoints.jl Features

- Flexible macro for simulating time series with changepoints
- Variety of parametric and non-parametric cost functions available

Changepoints.jl Features

- Flexible macro for simulating time series with changepoints
- Variety of parametric and non-parametric cost functions available
- Implementations of PELT, CROPS, and Binary Segmentation algorithms

Changepoints.jl Features

- Flexible macro for simulating time series with changepoints
- Variety of parametric and non-parametric cost functions available
- Implementations of PELT, CROPS, and Binary Segmentation algorithms
- Macros to allow intuitive specification of changepoint model

Changepoints.jl Features

- Flexible macro for simulating time series with changepoints
- Variety of parametric and non-parametric cost functions available
- Implementations of PELT, CROPS, and Binary Segmentation algorithms
- Macros to allow intuitive specification of changepoint model
- Functions for plotting changepoint output

Changepoints.jl Features

- Flexible macro for simulating time series with changepoints
- Variety of parametric and non-parametric cost functions available
- Implementations of PELT, CROPS, and Binary Segmentation algorithms
- Macros to allow intuitive specification of changepoint model
- Functions for plotting changepoint output
- R-style documentation

Changepoints.jl Features

- Flexible macro for simulating time series with changepoints
- Variety of parametric and non-parametric cost functions available
- Implementations of PELT, CROPS, and Binary Segmentation algorithms
- Macros to allow intuitive specification of changepoint model
- Functions for plotting changepoint output
- R-style documentation
- Rigourous unit tests

Installing Changepoints.jl

- To install the latest stable release of Julia on Ubuntu:

```
sudo add-apt-repository ppa:staticfloat/juliareleases
sudo apt-get update
sudo apt-get install julia
```

- To install Changepoints and optional Winston plotting package in Julia:

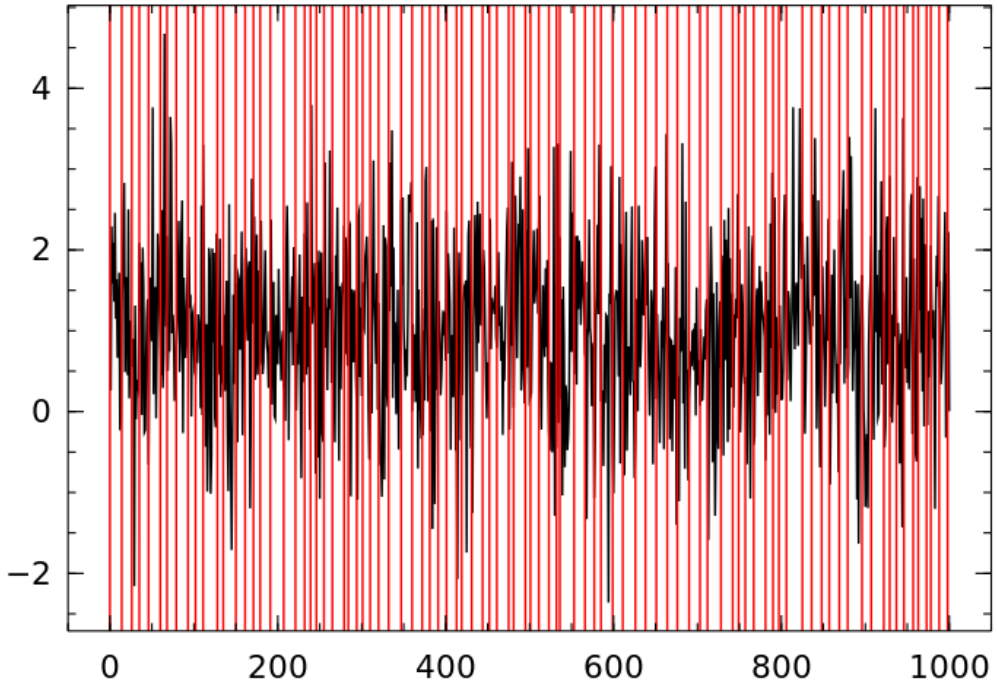
```
Pkg.add("Changepoints")
Pkg.add("Winston")
```

Simulating Changepoints

```
using Winston, Changepoints
μ, σ = Uniform(-5.0, 5.0), 1.0
n = 1000    # Length of sample
λ = 10      # Frequency of changes
data, cps = @changepoint_sampler n λ Normal(μ, σ)
plot(data, cps)
```

Simulating Changepoints

```
using Winston, Changepoints
μ, σ = Uniform(-5.0, 5.0), 1.0
n = 1000    # Length of sample
λ = 10      # Frequency of changes
data, cps = @changepoint_sampler n λ Normal(μ, σ)
plot(data, cps)
```



Finding Changepoints

- Currently PELT and binary segmentation have been implemented
- Both algorithms have a uniform interface for all cost functions

```
# Create cost function
seg_cost = NormalMeanSegment(data, σ)
# Run PELT on cost function
pelt_cps, pelt_cost = PELT(seg_cost, n)
# Run Binary segmentation on cost function
bs_cps, bs_cost = BS(seg_cost, n)
```

Creating cost functions

- A cost function is simply any function which takes two indices and returns the cost between

Creating cost functions

- A cost function is simply any function which takes two indices and returns the cost between
- $C(y_{s:t}) = -2 \log p(y_{s:t}|\hat{\theta})$ for all s and t.

Creating cost functions

- A cost function is simply any function which takes two indices and returns the cost between
- $C(y_{s:t}) = -2 \log p(y_{s:t}|\hat{\theta})$ for all s and t.
- Adding new cost functions is therefore very easy

Creating cost functions

- A cost function is simply any function which takes two indices and returns the cost between
- $C(y_{s:t}) = -2 \log p(y_{s:t}|\hat{\theta})$ for all s and t.
- Adding new cost functions is therefore very easy

Creating cost functions

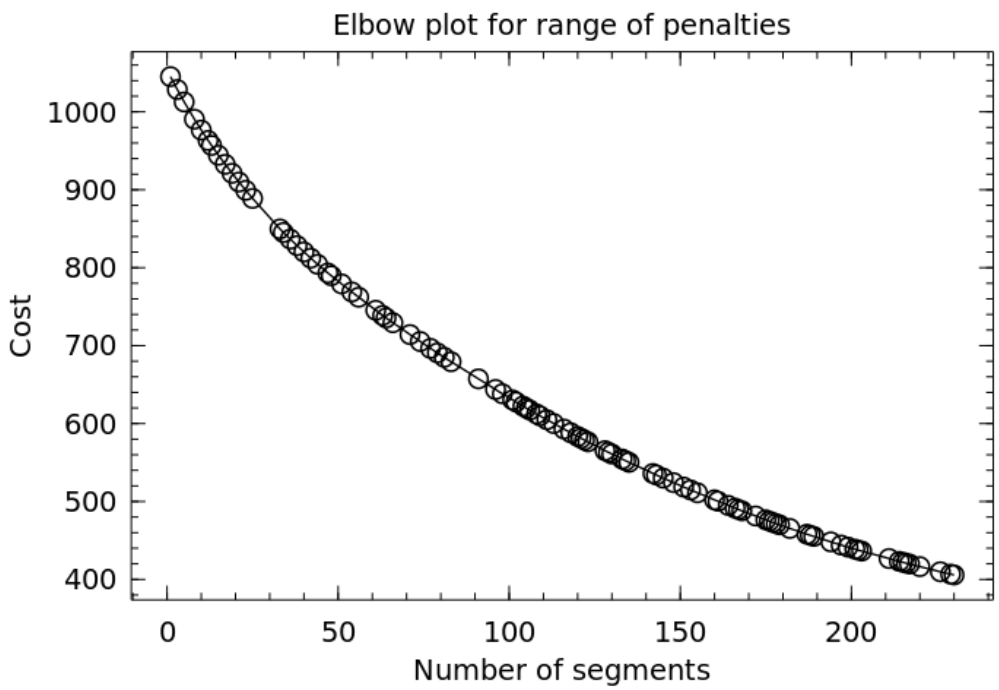
- A cost function is simply any function which takes two indices and returns the cost between
- $C(y_{s:t}) = -2 \log p(y_{s:t}|\hat{\theta})$ for all s and t.
- Adding new cost functions is therefore very easy

```
function NormalMeanSegment(data::Array{Float64}, σ::Real = 1.0)
  cd = [0,cumsum( data )]
  cd_2 = [0,cumsum( abs2(data) )]
  function cost(s::Int64, t::Int64)
    (cd_2[t+1] - cd_2[s+1] - abs2(cd[t+1] - cd[s+1])/(t-s))/(σ^2)
  end
  return cost
end
```

- Other functions to construct segment cost functions:
  `NormalVarSegment`, `NormalMeanVarSegment`
  `PoissonSegment`, `ExponentialSegment`, `NonparametricSegment`
  `GammaRateSegment`, `GammaShapeSegment`

Changepoints for range of penalties (CROPS)

```
# Set penalty range
β1, β2 = 1.0, 10.0
# Run CROPS
crops_out = CROPS(seg_cost, n, (β1, β2))
plot(crops_out)
```



Changepoint macros

- Macros allow direct specification of Changepoint model

```
# Run PELT with default penalty
pelt_cps, pelt_cost = @PELT data Normal(?, σ)
# Run PELT with specified penalty
pelt_cps, pelt_cost = @PELT data Normal(?, σ) β1
# Run CROPS
crops_output = @PELT data Normal(?, σ) β1 β2
```

Changepoint Model	**Cost function**
Normal(?, σ)	NormalMeanSegment
Normal(μ, ?)	NormalVarSegment
Normal(?, ?)	NormalMeanVarSegment
Gamma(?, β)	GammaShapeSegment
Gamma(α, ?)	GammaRateSegment
Exponential(?)	ExponentialSegment
Poisson(?)	PoissonSegment
Nonparametric(k)	Nonparametric

Accessing documentation

```
julia> Pkg.add("Lexicon")
julia> using Lexicon
julia> ?
help?> @PELT

Changepoints.@PELT(data, dist, args...)

  Runs the PELT algorithm using a specified cost function and pena
  find the position and number of changepoints

                                  Usage
                                 _                 _

  1. @PELT data changepoint_model: Run PELT with default penalty v

  2. @PELT data changepoint_model β: Run PELT at penalty value β
  ...
```

- From Julia v0.4 documentation will be directly accessible

Version 0.2 - Potential enhancements

- Add C version of PELT

Version 0.2 - Potential enhancements

- Add C version of PELT
- Implement recycling for CROPS

Version 0.2 - Potential enhancements

- Add C version of PELT
- Implement recycling for CROPS
- Implement FPOP

Version 0.2 - Potential enhancements

- Add C version of PELT
- Implement recycling for CROPS
- Implement FPOP
- Bayesian - Can calculate the posterior using a set of recursions (Forward-backward algorithm). Like the cost we calculate the marginal likelihood but we have a prior on any parameters of the model $\pi(\theta)$

$$\int p(y_{s:t}|\theta)\pi(\theta)\, d\theta$$

and some prior distribution for the distance between changepoints.

Version 0.2 - Potential enhancements

- Add C version of PELT
- Implement recycling for CROPS
- Implement FPOP
- Bayesian - Can calculate the posterior using a set of recursions (Forward-backward algorithm). Like the cost we calculate the marginal likelihood but we have a prior on any parameters of the model $\pi(\theta)$

$$\int p(y_{s:t}|\theta)\pi(\theta)\, d\theta$$

  and some prior distribution for the distance between changepoints.
- What else?

Getting involved

- Code can viewed and downloaded from `https://github.com/STOR-i/Changepoints.jl`
- You will need a Github account to make changes to the package

Any Questions?

Performance

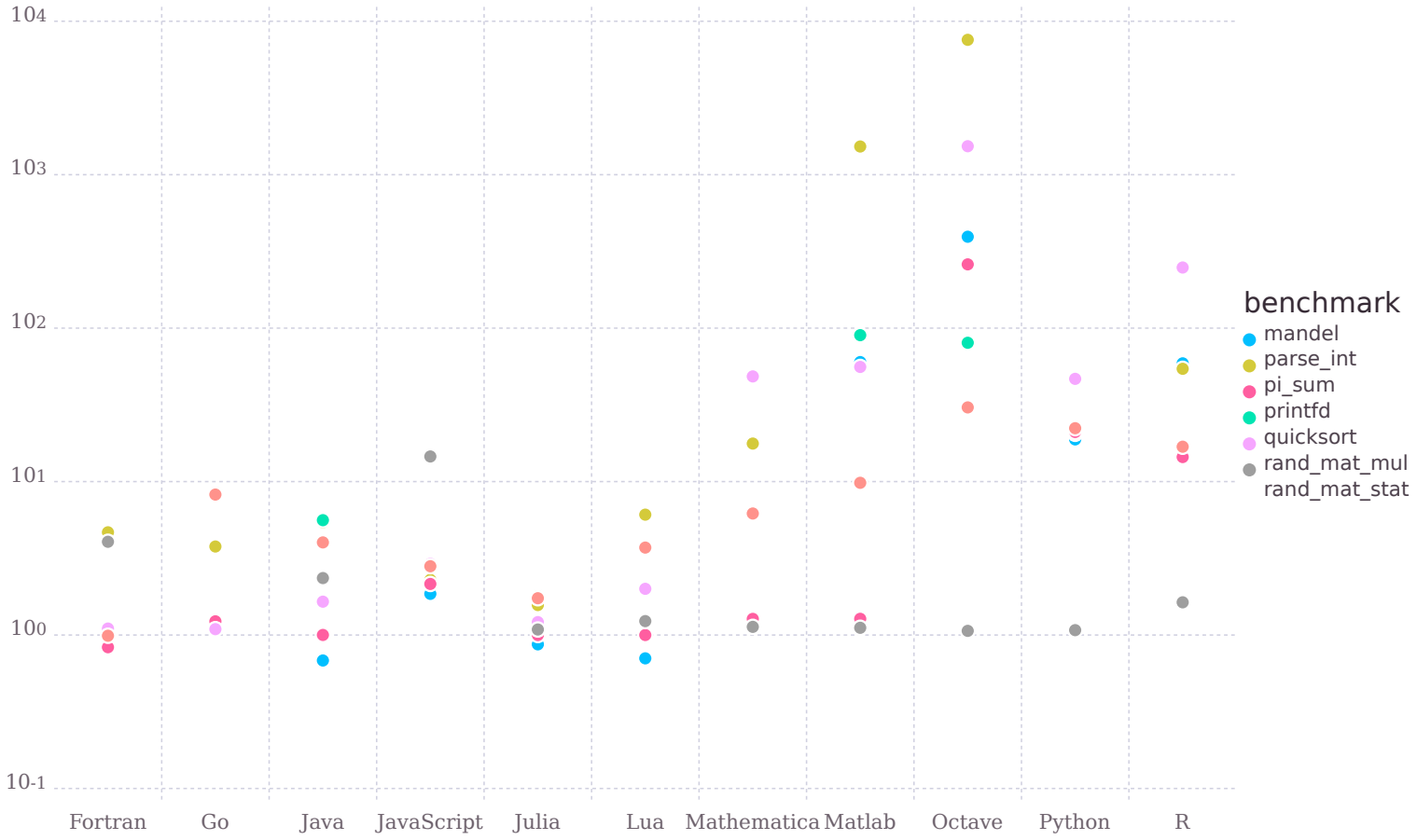


Figure : Benchmark times relative to C from julialang.org (smaller is better, C performance = 1.0)