Jump process

Simon Frost (@sdwfrost), 2020-04-27

Introduction

This implementation defines the model as a combination of two jump processes, infection and recovery, simulated using the Doob-Gillespie algorithm.

Libraries

```
using DifferentialEquations
using SimpleDiffEq
using Random
using DataFrames
using StatsPlots
using BenchmarkTools
```

Transitions

For each process, we define the rate at which it occurs, and how the state variables change at each jump. Note that these are total rates, not *per capita*, and that the change in state variables occurs in-place.

```
function infection_rate(u,p,t)
    (S,I,R) = u
    (β,c,γ) = p
    N = S+I+R
    β*c*I/N*S
end
function infection!(integrator)
  integrator.u[1] -= 1
  integrator.u[2] += 1
end
infection_jump = ConstantRateJump(infection_rate,infection!);
```

```
ConstantRateJump{typeof(Main.##WeaveSandBox#531.infection_rate),typeof(Main
.##WeaveSandBox#531.infection!)}(Main.##WeaveSandBox#531.infection_rate, Ma
in.##WeaveSandBox#531.infection!)
```

```
function recovery_rate(u,p,t)
    (S,I,R) = u
    (β,c,γ) = p
    γ*I
end
function recovery!(integrator)
  integrator.u[2] -= 1
  integrator.u[3] += 1
end
recovery_jump = ConstantRateJump(recovery_rate,recovery!);
```

```
ConstantRateJump{typeof(Main.##WeaveSandBox#531.recovery_rate),typeof(Main.
##WeaveSandBox#531.recovery!)}(Main.##WeaveSandBox#531.recovery_rate, Main.
##WeaveSandBox#531.recovery!)
```

Time domain

```
tmax = 40.0
tspan = (0.0,tmax);
```

```
(0.0, 40.0)
```

For plotting, we can also define a separate time series.

```
δt = 0.1
t = 0:δt:tmax;
```

```
0.0:0.1:40.0
```

Initial conditions

```
u0 = [990,10,0]; # S,I,R
```

```
3-element Array{Int64,1}:
 990
  10
   0
```

Parameter values

```
p = [0.05,10.0,0.25]; # β,c,γ
```

```
3-element Array{Float64,1}:
  0.05
 10.0
  0.25
```

Random number seed

We set a random number seed for reproducibility.

```
Random.seed!(1234);
```

```
MersenneTwister(UInt32[0x000004d2], Random.DSFMT.DSFMT_state(Int32[-1393240
018, 1073611148, 45497681, 1072875908, 436273599, 1073674613, -2043716458,
1073445557, -254908435, 1072827086  …  -599655111, 1073144102, 367655457, 1
072985259, -1278750689, 1018350124, -597141475, 249849711, 382, 0]), [0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0  …  0.0, 0.0, 0.0, 0.0, 0.0, 0.
0, 0.0, 0.0, 0.0, 0.0], UInt128[0x00000000000000000000000000000000, 0x00000
000000000000000000000000000, 0x00000000000000000000000000000000, 0x00000000
000000000000000000000000, 0x00000000000000000000000000000000, 0x00000000000
000000000000000000000, 0x00000000000000000000000000000000, 0x00000000000000
000000000000000000, 0x00000000000000000000000000000000, 0x00000000000000000
000000000000000  …  0x00000000000000000000000000000000, 0x00000000000000000
000000000000000, 0x00000000000000000000000000000000, 0x00000000000000000000
000000000000, 0x00000000000000000000000000000000, 0x00000000000000000000000
000000000, 0x00000000000000000000000000000000, 0x00000000000000000000000000
000000, 0x00000000000000000000000000000000, 0x00000000000000000000000000000
000], 1002, 0)
```

Running the model

Running this model involves:

- Setting up the problem as a `DiscreteProblem`;
- Adding the jumps and setting the algorithm using `JumpProblem`; and
- Running the model, specifying `SSAStepper()`

```
prob = DiscreteProblem(u0,tspan,p)
```

```
DiscreteProblem with uType Array{Int64,1} and tType Float64. In-place: true
timespan: (0.0, 40.0)
u0: [990, 10, 0]
```

```
prob_jump = JumpProblem(prob,Direct(),infection_jump,recovery_jump)
```

```
JumpProblem with problem DiscreteProblem and aggregator Direct
Number of constant rate jumps: 2
Number of variable rate jumps: 0
```

```
sol_jump = solve(prob_jump,SSAStepper());
```

```
retcode: Default
Interpolation: Piecewise constant interpolation
t: 1456-element Array{Float64,1}:
  0.0
  0.06893377317072444
  0.3503237889828664
  0.44259027583687194
  0.5179915289715358
  0.5273195527211588
  0.6568941454896076
  0.8084842454458481
  0.842185027224201
  0.8727358159131361
  ⋮
 38.625626769056076
 38.662086030538624
 38.75984572014
 38.81257973946912
 39.000968932230535
 39.161262411082994
 39.62415062412911
 39.98863269937939
 40.0
u: 1456-element Array{Array{Int64,1},1}:
 [990, 10, 0]
 [989, 11, 0]
 [988, 12, 0]
 [987, 13, 0]
 [986, 14, 0]
 [985, 15, 0]
 [985, 14, 1]
 [984, 15, 1]
 [983, 16, 1]
```

```
 [983, 15, 2]
 ⋮
 [264, 15, 721]
 [264, 14, 722]
 [264, 13, 723]
 [264, 12, 724]
 [264, 11, 725]
 [264, 10, 726]
 [263, 11, 726]
 [263, 10, 727]
 [263, 10, 727]
```

Post-processing

In order to get output comparable across implementations, we output the model at a fixed set of times.

```
out_jump = sol_jump(t);
```

```
t: 0.0:0.1:40.0
u: 401-element Array{Array{Int64,1},1}:
 [990, 10, 0]
 [989, 11, 0]
 [989, 11, 0]
 [989, 11, 0]
 [988, 12, 0]
 [987, 13, 0]
 [985, 15, 0]
 [985, 14, 1]
 [985, 14, 1]
 [983, 15, 2]
 ⋮
 [264, 10, 726]
 [264, 10, 726]
 [264, 10, 726]
 [264, 10, 726]
 [264, 10, 726]
 [263, 11, 726]
 [263, 11, 726]
 [263, 11, 726]
 [263, 10, 727]
```

We can convert to a dataframe for convenience.

```
df_jump = DataFrame(out_jump')
df_jump[!,:t] = out_jump.t;
```

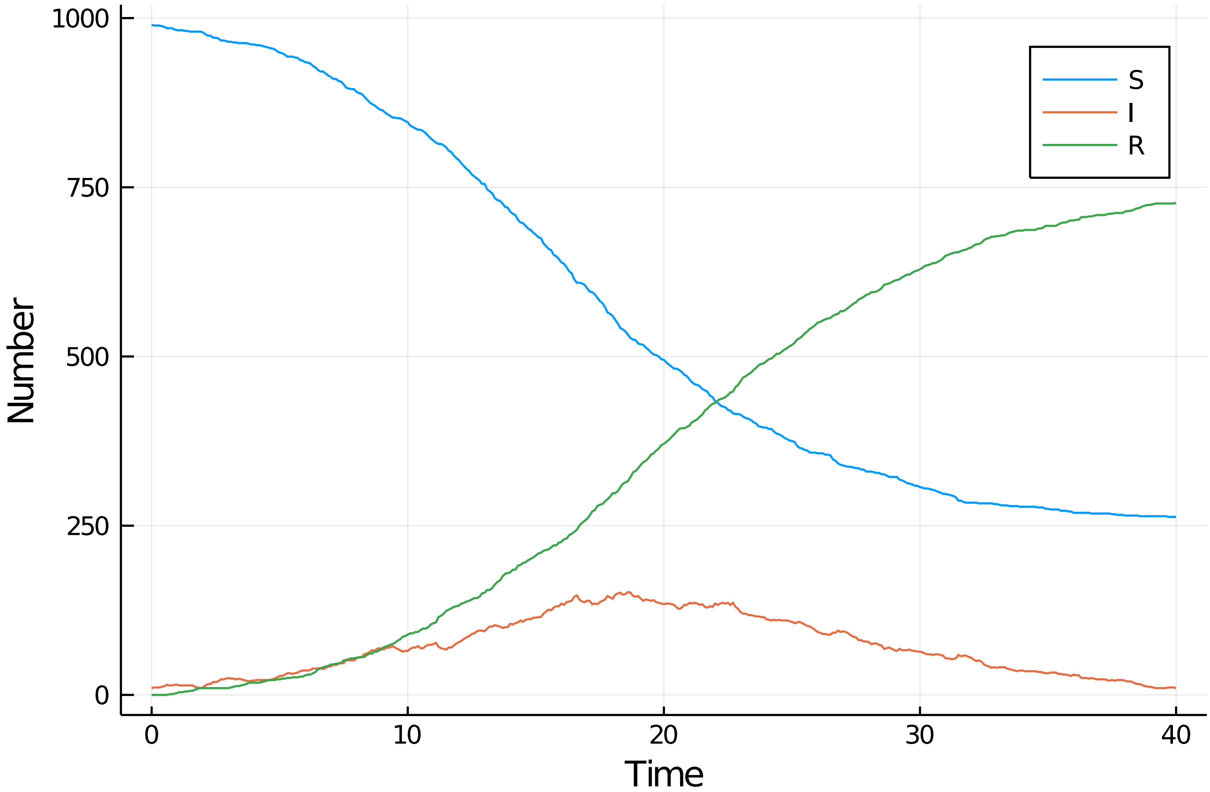
```
0.0:0.1:40.0
```

Plotting

We can now plot the results.

```
@df df_jump plot(:t,
    [:x1 :x2 :x3],
```

```
    label=["S" "I" "R"],
    xlabel="Time",
    ylabel="Number")
```



Benchmarking

```
@benchmark solve(prob_jump,FunctionMap())
```

```
BenchmarkTools.Trial:
  memory estimate:  12.47 KiB
  allocs estimate:  107
  --------------
  minimum time:     11.539 μs (0.00% GC)
  median time:      514.490 μs (0.00% GC)
  mean time:        581.341 μs (10.82% GC)
  maximum time:     17.500 ms (94.76% GC)
  --------------
  samples:          8568
  evals/sample:     1
```

Appendix

Computer Information

```
Julia Version 1.4.1
Commit 381693d3df* (2020-04-14 17:20 UTC)
Platform Info:
  OS: Linux (x86_64-pc-linux-gnu)
  CPU: Intel(R) Core(TM) i7-1065G7 CPU @ 1.30GHz
```

```
  WORD_SIZE: 64
  LIBM: libopenlibm
  LLVM: libLLVM-8.0.1 (ORCJIT, icelake-client)
Environment:
  JULIA_NUM_THREADS = 4
```

Package Information

```
Status `~/.julia/environments/v1.4/Project.toml`
[46ada45e-f475-11e8-01d0-f70cc89e6671] Agents 3.1.0
[c52e3926-4ff0-5f6e-af25-54175e0327b1] Atom 0.12.11
[6e4b80f9-dd63-53aa-95a3-0cdb28fa8baf] BenchmarkTools 0.5.0
[a134a8b2-14d6-55f6-9291-3336d3ab0209] BlackBoxOptim 0.5.0
[2445eb08-9709-466a-b3fc-47e12bd697a2] DataDrivenDiffEq 0.2.0
[a93c6f00-e57d-5684-b7b6-d8193f3e46c0] DataFrames 0.21.0
[ebbdde9d-f333-5424-9be2-dbf1e9acfb5e] DiffEqBayes 2.14.0
[459566f4-90b8-5000-8ac3-15dfb0a30def] DiffEqCallbacks 2.13.2
[c894b116-72e5-5b58-be3c-e6d8d4ac2b12] DiffEqJump 6.7.5
[1130ab10-4a5a-5621-a13d-e4788d82bd4c] DiffEqParamEstim 1.14.1
[0c46a032-eb83-5123-abaf-570d42b7fbaa] DifferentialEquations 6.14.0
[31c24e10-a181-5473-b8eb-7969acd0382f] Distributions 0.23.2
[634d3b9d-ee7a-5ddf-bec9-22491ea816e1] DrWatson 1.11.0
[587475ba-b771-5e3f-ad9e-33799f191a9c] Flux 0.8.3
[28b8d3ca-fb5f-59d9-8090-bfdbd6d07a71] GR 0.49.1
[523d8e89-b243-5607-941c-87d699ea6713] Gillespie 0.1.0
[7073ff75-c697-5162-941a-fcdaad2a7d2a] IJulia 1.21.2
[4076af6c-e467-56ae-b986-b466b2749572] JuMP 0.21.2
[e5e0dc1b-0480-54bc-9374-aad01c23163d] Juno 0.8.2
[093fc24a-ae57-5d10-9952-331d41423f4d] LightGraphs 1.3.3
[1914dd2f-81c6-5fcd-8719-6d5c9610ff09] MacroTools 0.5.5
[ee78f7c6-11fb-53f2-987a-cfe4a2b5a57a] Makie 0.9.5
[961ee093-0014-501f-94e3-6117800e7a78] ModelingToolkit 3.6.0
[76087f3c-5699-56af-9a33-bf431cd00edd] NLopt 0.6.0
[429524aa-4258-5aef-a3af-852621145aeb] Optim 0.21.0
[1dea7af3-3e70-54e6-95c3-0bf5283fa5ed] OrdinaryDiffEq 5.38.1
[91a5bcdd-55d7-5caf-9e0b-520d859cae80] Plots 1.3.1
[428bdadb-6287-5aa5-874b-9969638295fd] SimJulia 0.8.0
[05bca326-078c-5bf0-a5bf-ce7c7982d7fd] SimpleDiffEq 1.1.0
[f3b207a7-027a-5e70-b257-86293d7955fd] StatsPlots 0.14.6
[789caeaf-c7a9-5a7d-9973-96adeb23e2a0] StochasticDiffEq 6.23.0
[fce5fe82-541a-59a6-adf8-730c64b5f9a0] Turing 0.12.0
[44d3d7a6-8a23-5bf8-98c5-b353f8df5ec9] Weave 0.10.0
```