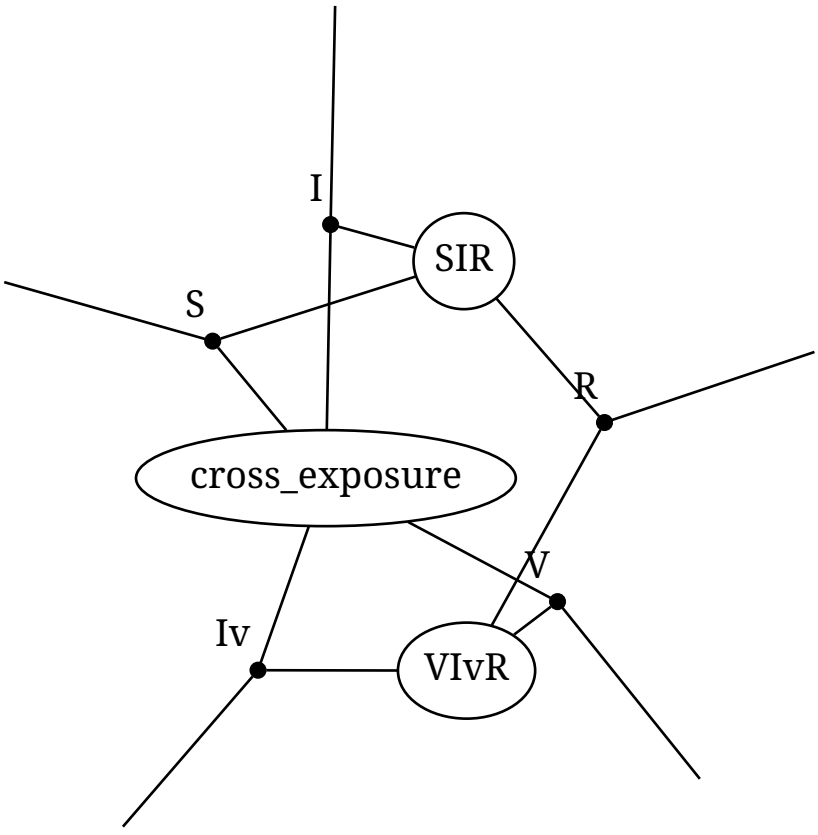
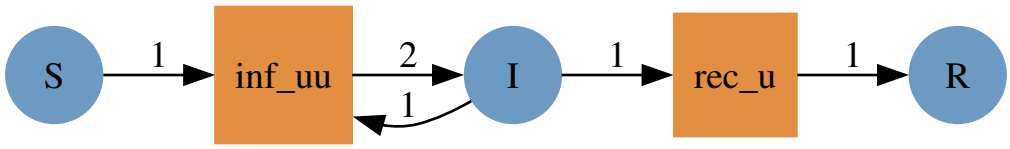
```
begin
    # import modules
    using Catlab, Catlab.CategoricalAlgebra, Catlab.Programs,
    Catlab.WiringDiagrams, Catlab.Graphics
    using AlgebraicPetri
    using AlgebraicDynamics.UWDDynam
    using DifferentialEquations
    using LabelledArrays
    using Plots
end
```

```
SVIIvR_composition_pattern = @relation (S, V, I, Iv, R) where (S, V, I, Iv, R) begin
SIR(S, I, R)
VIvR(V, Iv, R)
cross_exposure(S, I, V, Iv)
end;
```

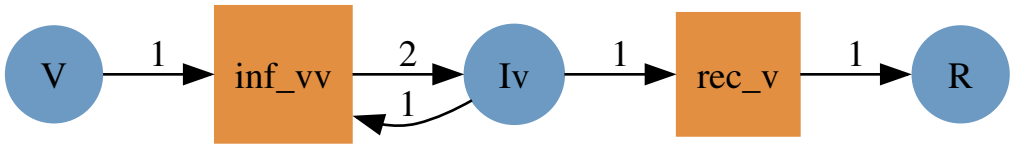



```
to_graphviz(SVIIvR_composition_pattern,
box_labels = :name, junction_labels = :variable, edge_attrs=Dict(:len => "1"))
```

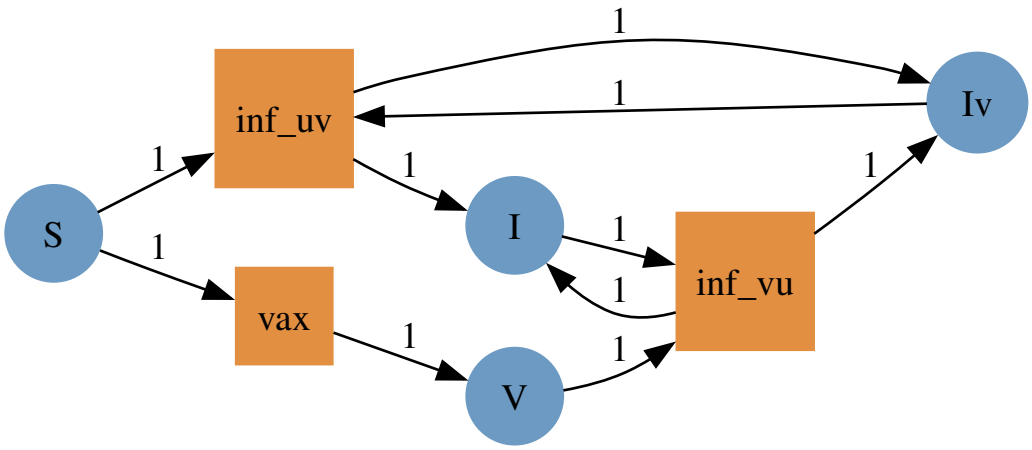
```
begin
    SIR = Open(LabelledPetriNet([:S, :I, :R],
    :inf_uu => ((:S, :I) => (:I, :I)),
    :rec_u => (:I => :R)
    ))
    VIvR = Open(LabelledPetriNet([:V, :Iv, :R],
    :inf_vv => ((:V, :Iv) => (:Iv, :Iv)),
    :rec_v => (:Iv => :R)
    ))
    cross_exposure = Open(LabelledPetriNet([:S, :I, :V, :Iv],
    :inf_uv => ((:S, :Iv) => (:I, :Iv)),
    :inf_vu => ((:V, :I) => (:Iv, :I)),
    :vax => (:S => :V)
    ))
    SVIIvR = oapply(SVIIvR_composition_pattern, Dict(
    :SIR => SIR,
    :VIvR => VIvR,
    :cross_exposure => cross_exposure
    )) |> apex
end;
```



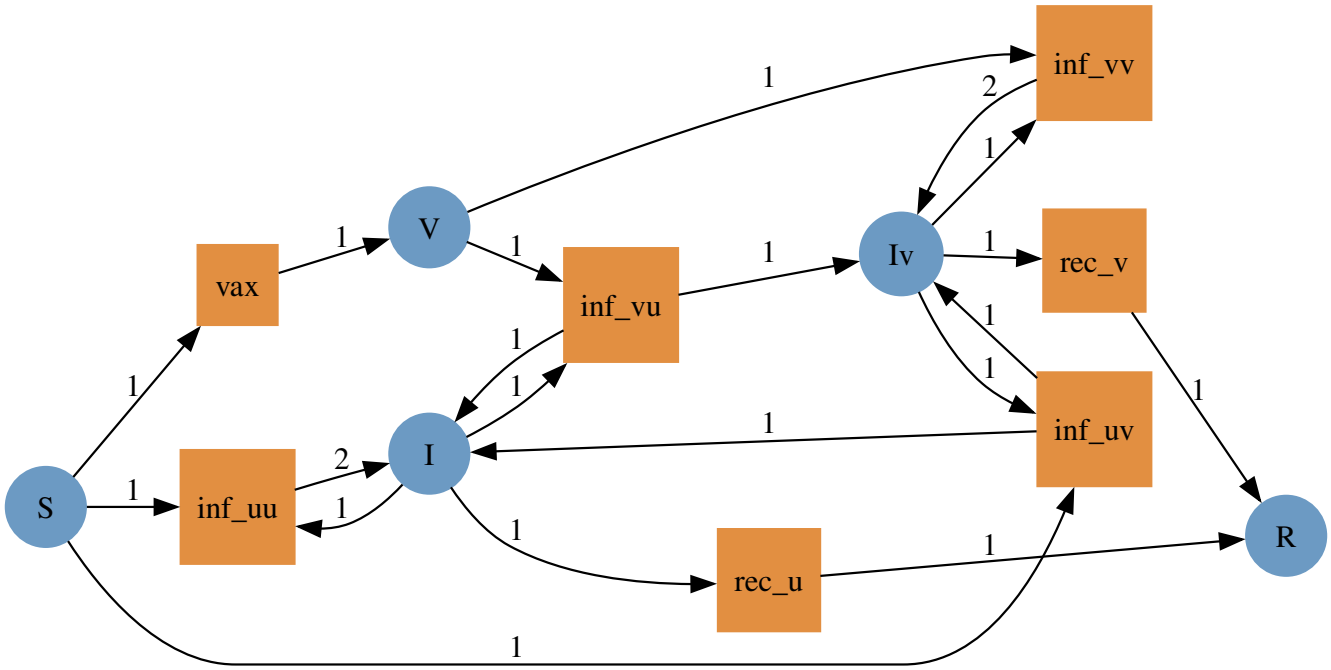

```
to_graphviz(SIR)
```




```
to_graphviz(VIvR)
```




```
to_graphviz(cross_exposure)
```

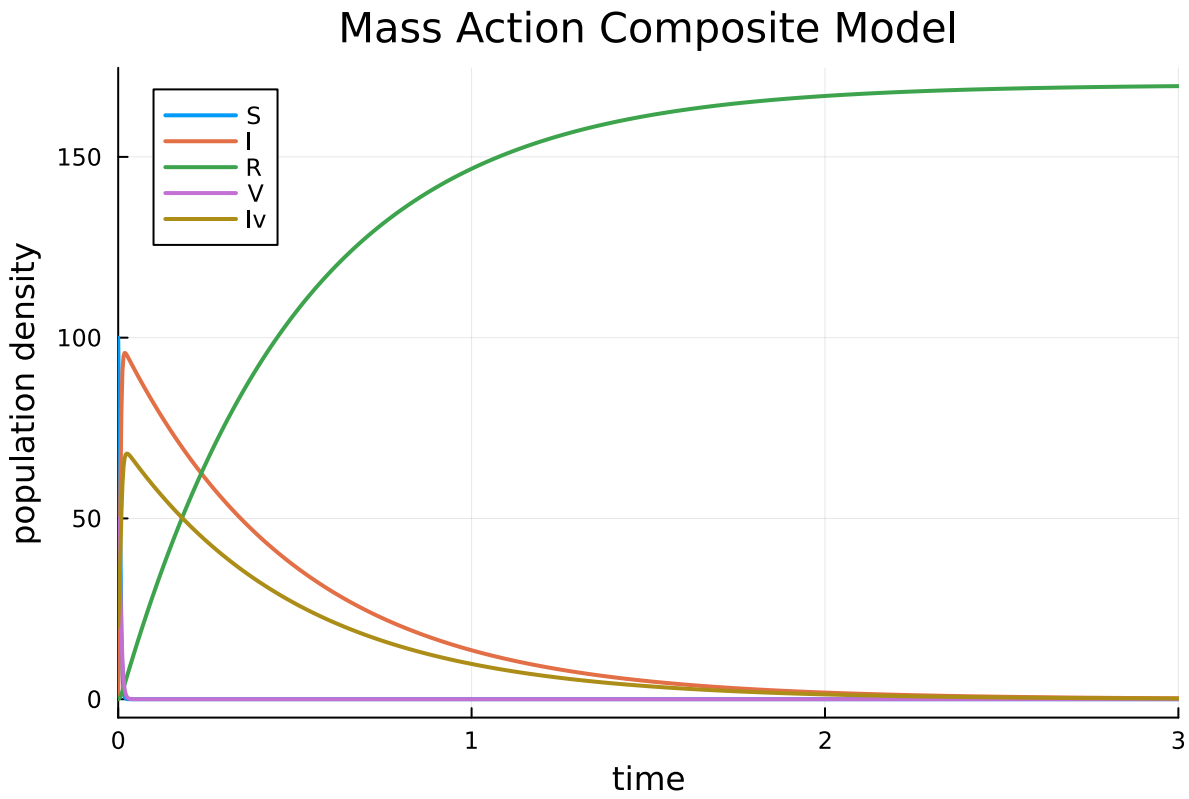



```
to_graphviz(SVIIvR)
```

```
begin
    params = LVector(inf_uu = 2, rec_u = 2,
                     inf_vv = 2, rec_v = 2,
                     inf_uv = 3, inf_vu = 1,
                     vax = 2)
    u0 = LVector(S = 100, I = 0, R = 0, V = 50, Iv = 20)
    tspan = (0., 3.)
end;
```

```
prob = ODEProblem(SVIIvR, u0, tspan, params);
```

```
sol = solve(prob, Tsit5());
```




```
plot(sol,
  lw = 2,
  label = ["S" "I" "R" "V" "Iv"],
  ylabel = "population density", xlabel = "time",
  title = "Mass Action Composite Model"
)
```

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