

AlgebraicPetri: COEXIST COVID-19 Model

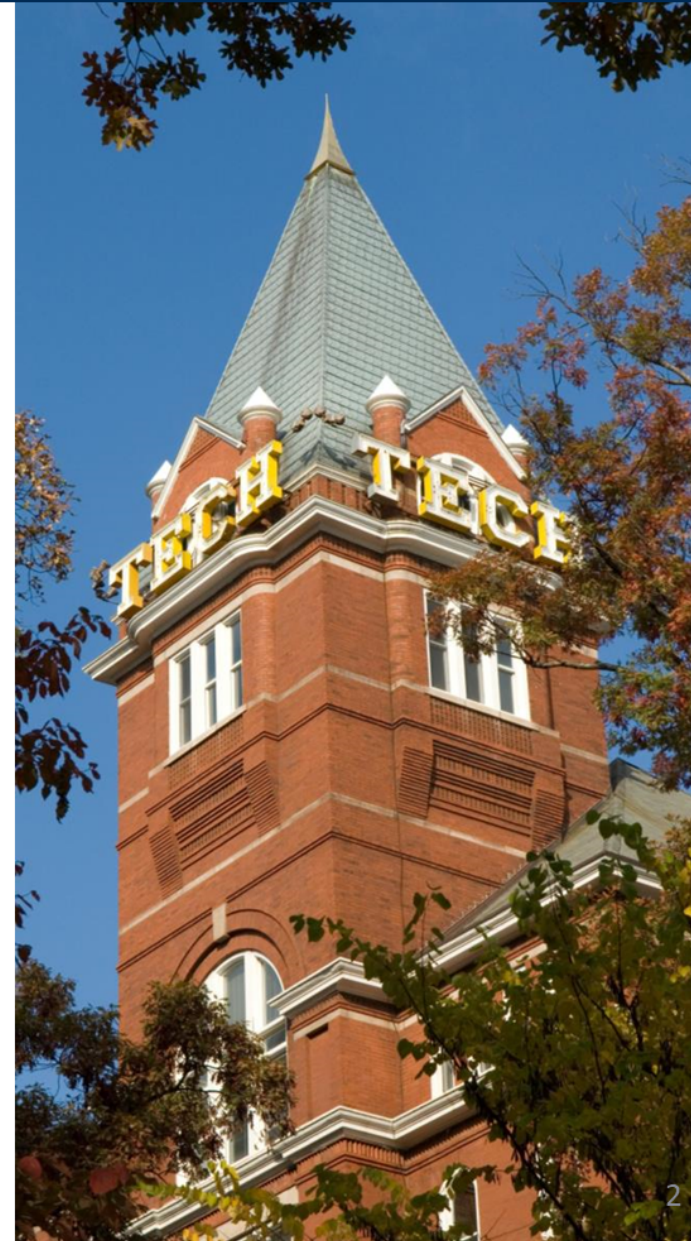
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Agenda

1. Defining the theory of epidemiology
2. Basic epidemiology models
3. Extend basic epidemiology models
4. Build and simulate COEXIST COVID-19 model

Defining the Theory of Epidemiology

```
@present InfectiousDiseases(FreeBiprodutCategory) begin
  S::Ob
  E::Ob
  I::Ob
  R::Ob
  D::Ob
  transmission::Hom(S⊗I, I)
  exposure::Hom(S⊗I, E)
  illness::Hom(E, I)
  recovery::Hom(I, R)
  death::Hom(I, D)
end
```

Epidemiology Building Blocks

Algebraic Expression

$$illness : E \rightarrow I$$

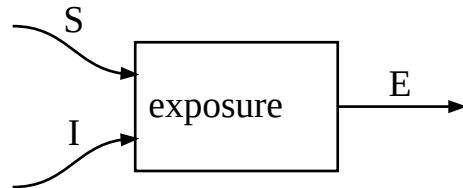
Wiring Diagram



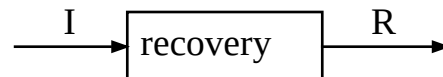
$$transmission : S \otimes I \rightarrow I$$



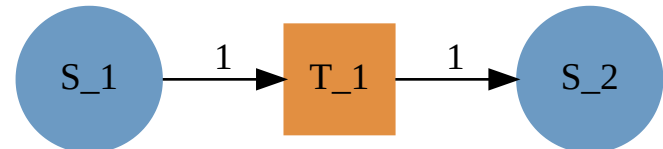
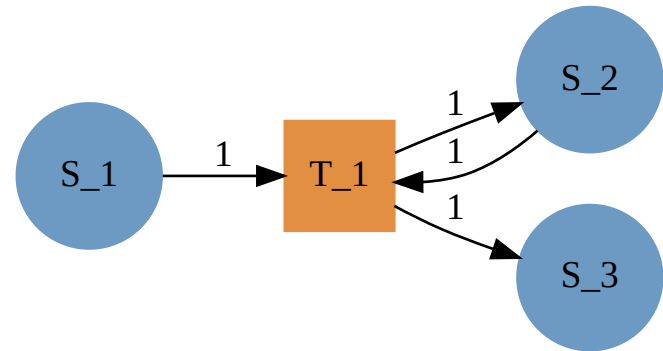
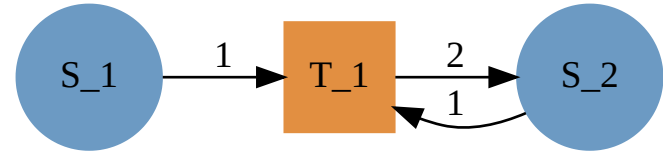
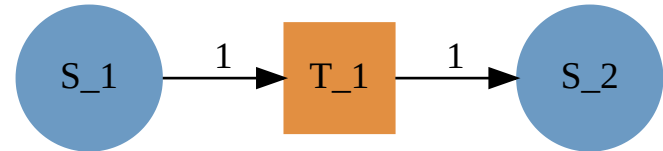
$$exposure : S \otimes I \rightarrow E$$



$$recovery : I \rightarrow R$$

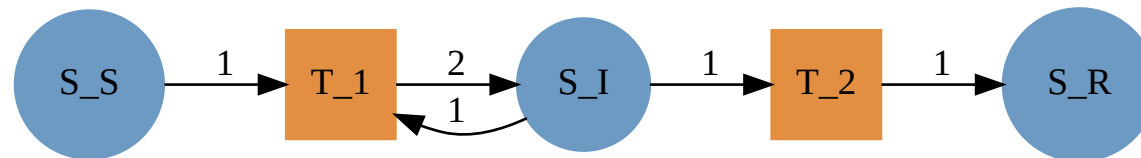
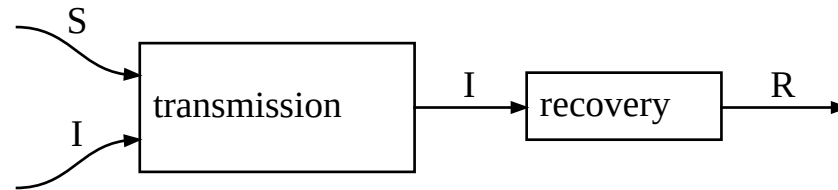


Petri Net



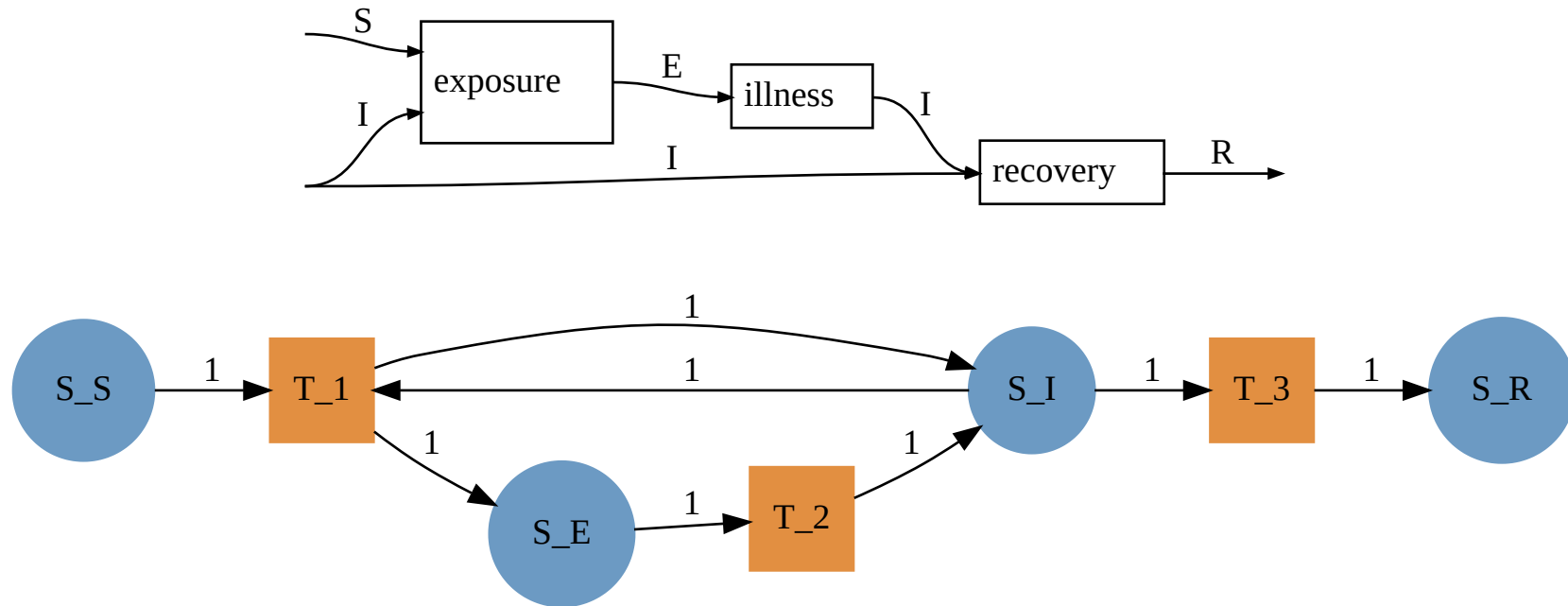
Basic SIR Model

$$sir = transmission \cdot recovery$$

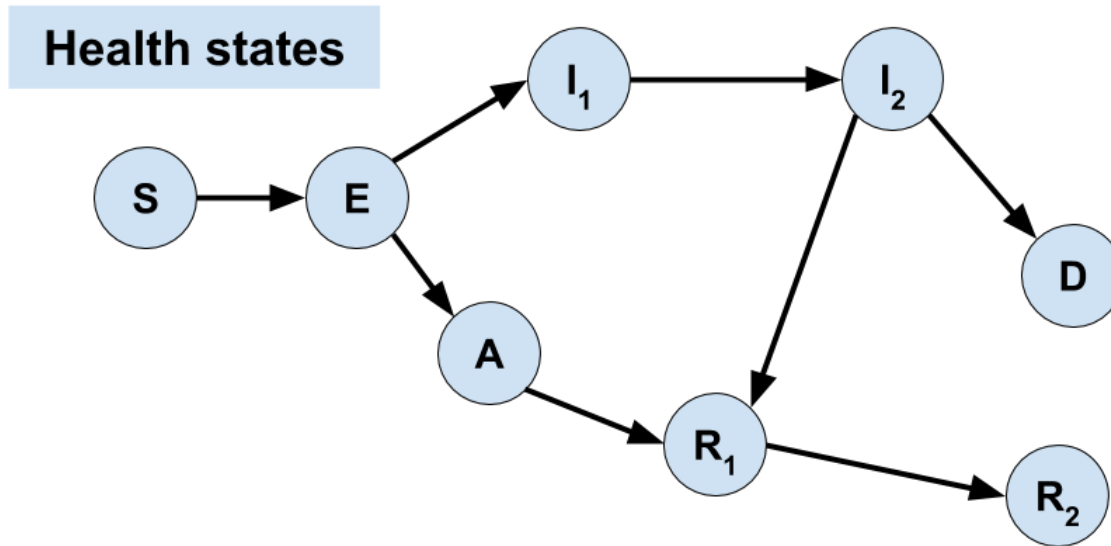


SEIR Model

```
seir = @program InfectiousDiseases (s::S,i::I) begin
  e = exposure(s,i)
  i2 = illness(e)
  i_all = [i,i2]
  return recovery(i_all)
end
```



COEXIST COVID-19 Model



Age states

0-9
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80+

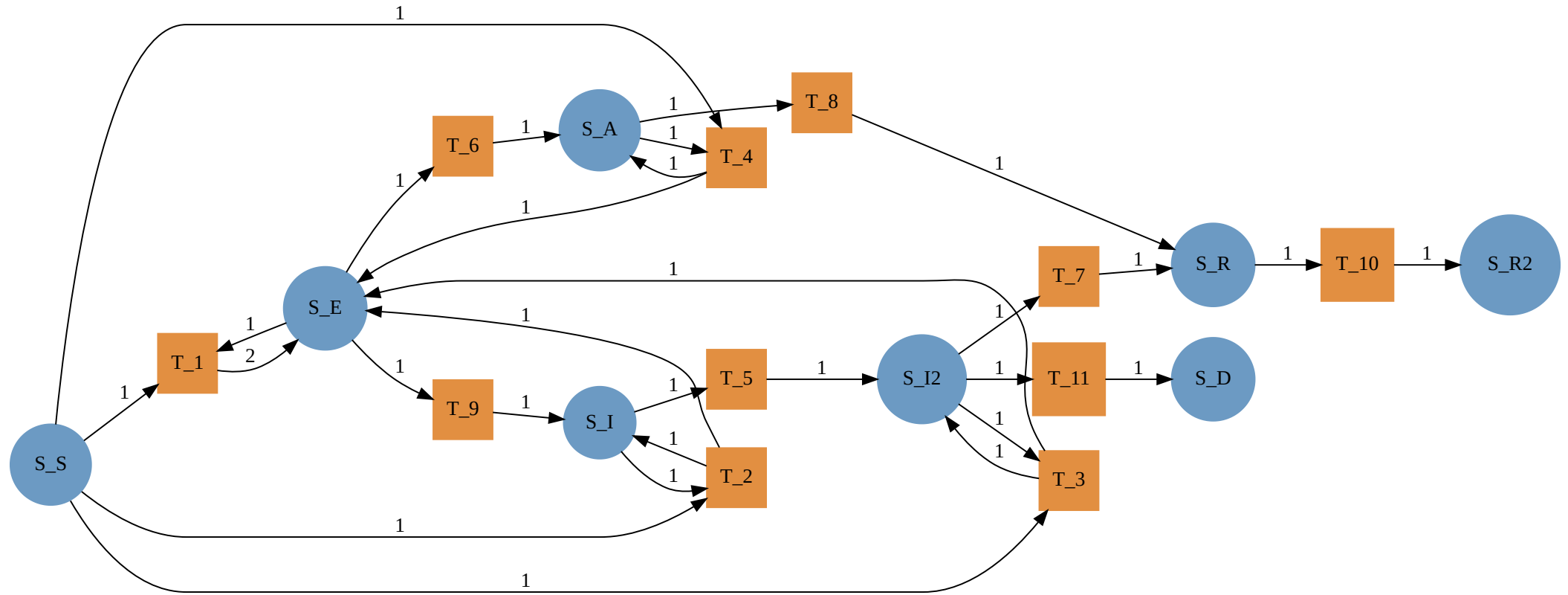
Extend Basic Epidemiology

```
@present EpiCoexist <: InfectiousDiseases begin
  I2::Ob
  A::Ob
  R2::Ob
  exposure_e::Hom( $S \otimes E$ , E)
  exposure_i2::Hom( $S \otimes I2$ , E)
  exposure_a::Hom( $S \otimes A$ , E)
  progression::Hom( $I$ , I2)
  asymptomatic_infection::Hom(E, A)
  recover_late::Hom(R, R2)
  asymptomatic_recovery::Hom(A, R)
  recovery2::Hom(I2, R)
  death2::Hom(I2, D)
end
```


Defining COEXIST

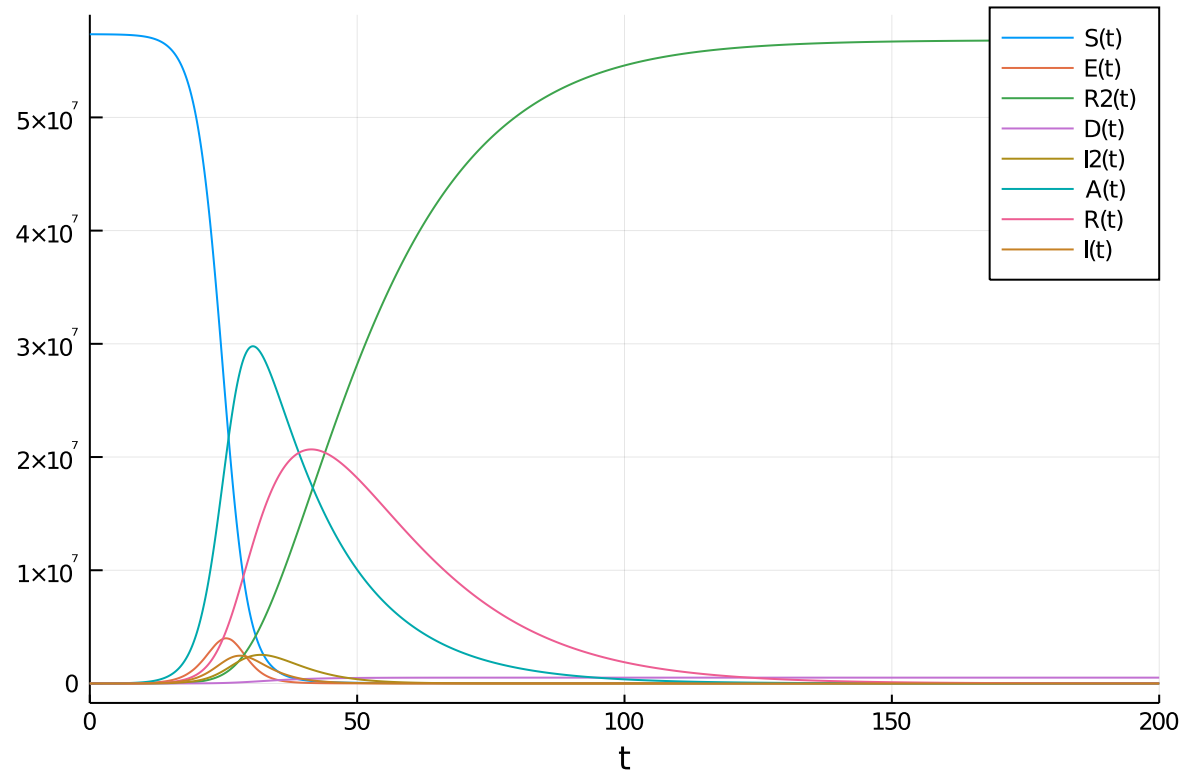
```
coexist = @program EpiCoexist (s::S, e::E, i::I, i2::I2, a::A, r::R, r2::R2, d::D) begin
    e_2 = exposure(s, i)
    e_3 = exposure_i2(s, i2)
    e_4 = exposure_a(s, a)
    e_5 = exposure_e(s, e)
    e_all = [e, e_2, e_3, e_4, e_5]
    a_2 = asymptomatic_infection(e_all)
    a_all = [a, a_2]
    r_2 = asymptomatic_recovery(a_all)
    i_2 = illness(e_all)
    i_all = [i, i_2]
    i2_2 = progression(i)
    i2_all = [i2, i2_2]
    d_2 = death2(i2_all)
    r_3 = recovery2(i2_all)
    r_all = [r, r_2, r_3]
    r2_2 = recover_late(r_all)
    r2_all = [r2, r2_2]
    d_all = [d, d_2]
    return s, e_all, i_all, i2_all, a_all, r_all, r2_all, d_all
end
```

COEXIST SEIRD Model Petri Net



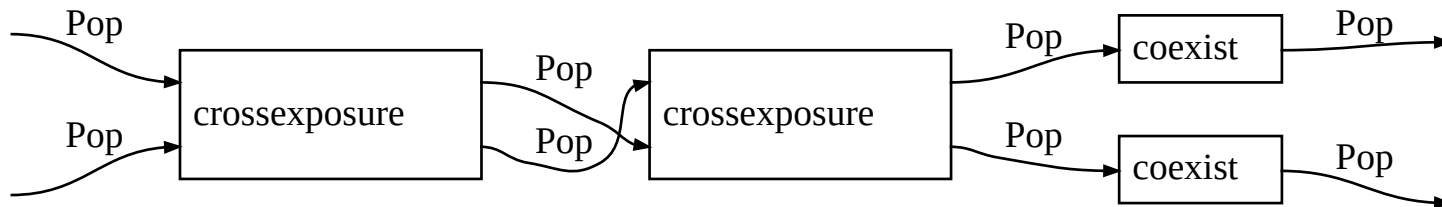
Simulate the Model

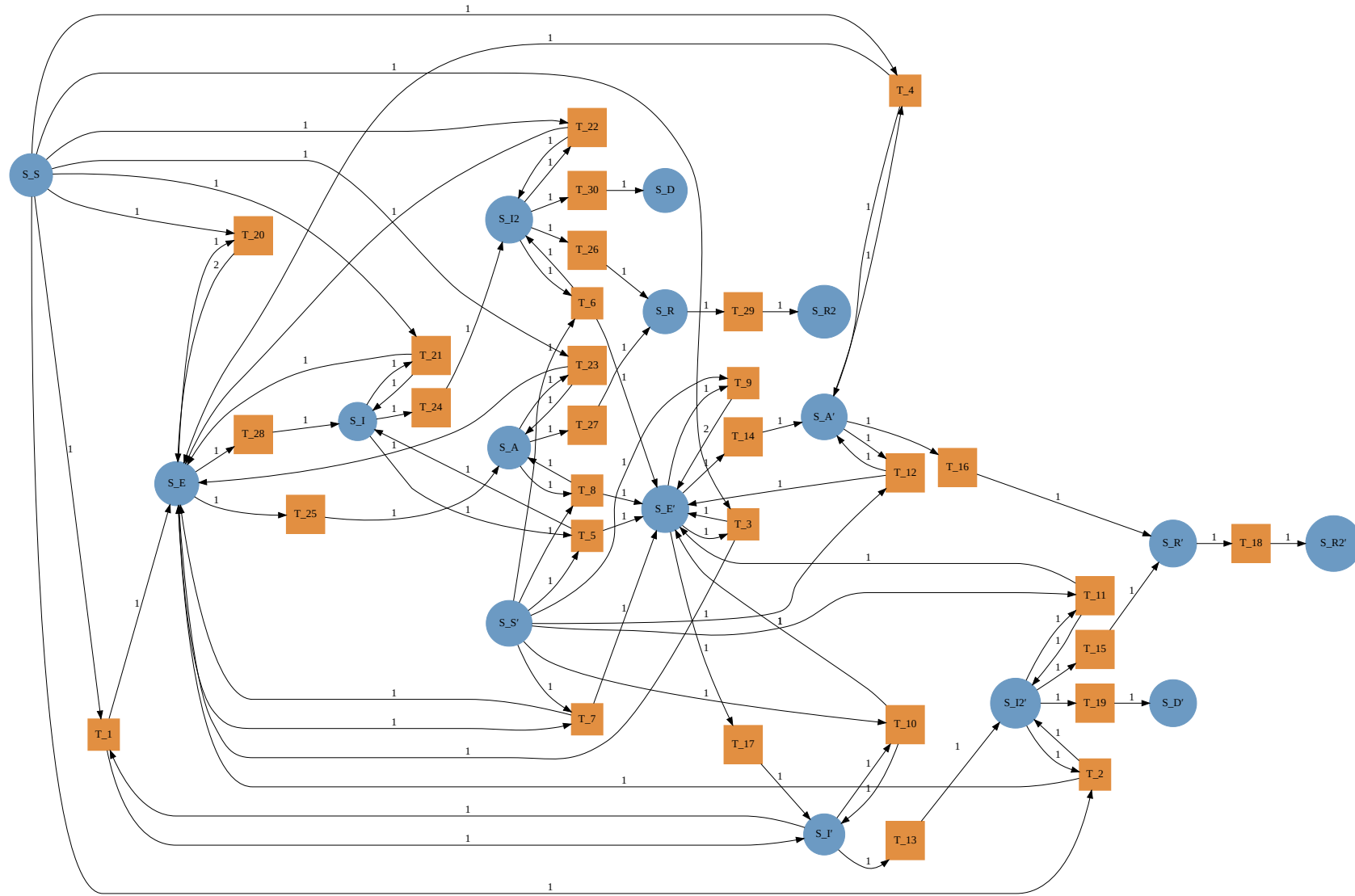
$u0.S = 57345080$
 $u0.E = 1000$
 $u0.I = 1000$
 $u0.I2 = 1000$
 $u0.A = 1000$



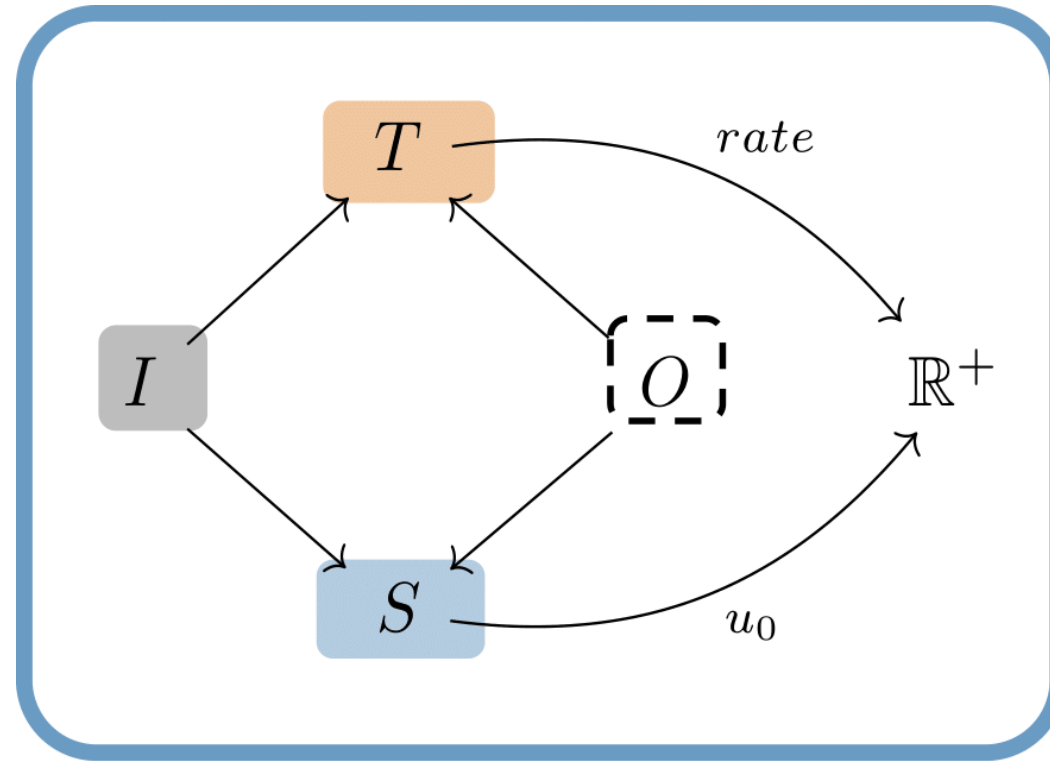
Define Inter-Generational Cross Exposure

```
crossexposure = @program EpiCoexist (s::S, e::E, i::I, i2::I2, a::A, r::R, r2::R2, d::D,  
                                     s'::S, e'::E, i'::I, i2'::I2, a'::A, r'::R, r2'::R2, d'::D) begin  
    e_2 = exposure(s, i')  
    e_3 = exposure_i2(s, i2')  
    e_4 = exposure_a(s, a')  
    e_5 = exposure_e(s, e')  
    e_all = [e, e_2, e_3, e_4, e_5]  
    return s, e_all, i, i2, a, r, r2, d,  
           s', e', i', i2', a', r', r2', d'  
end
```

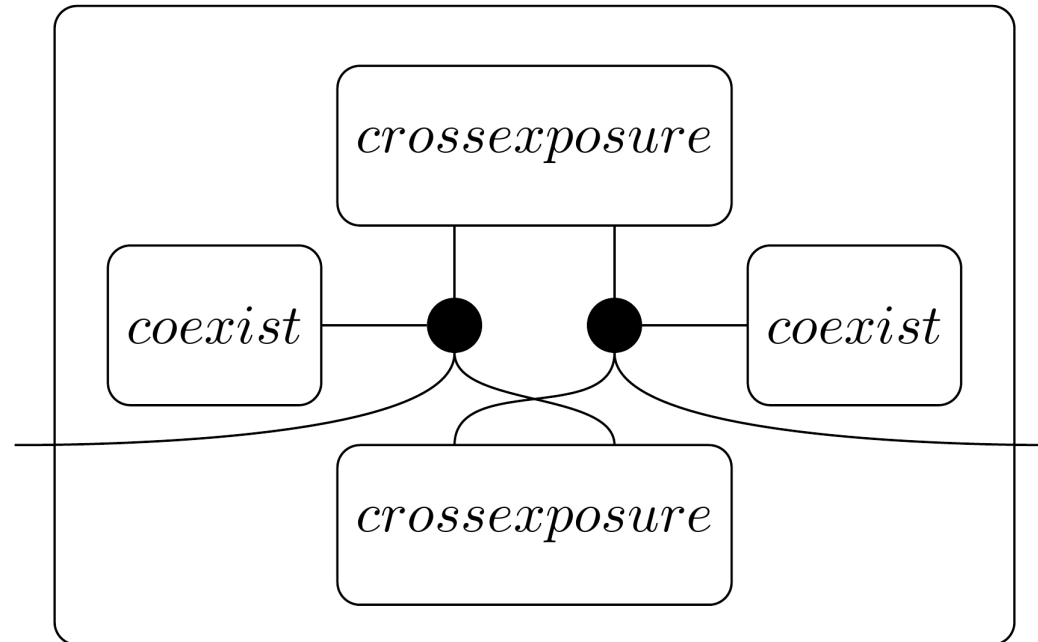
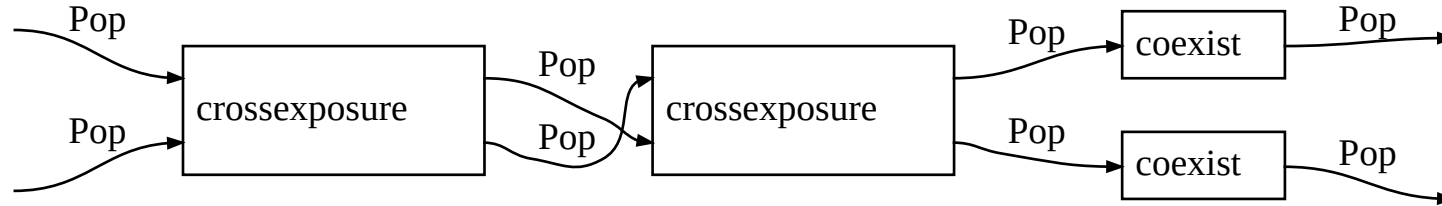




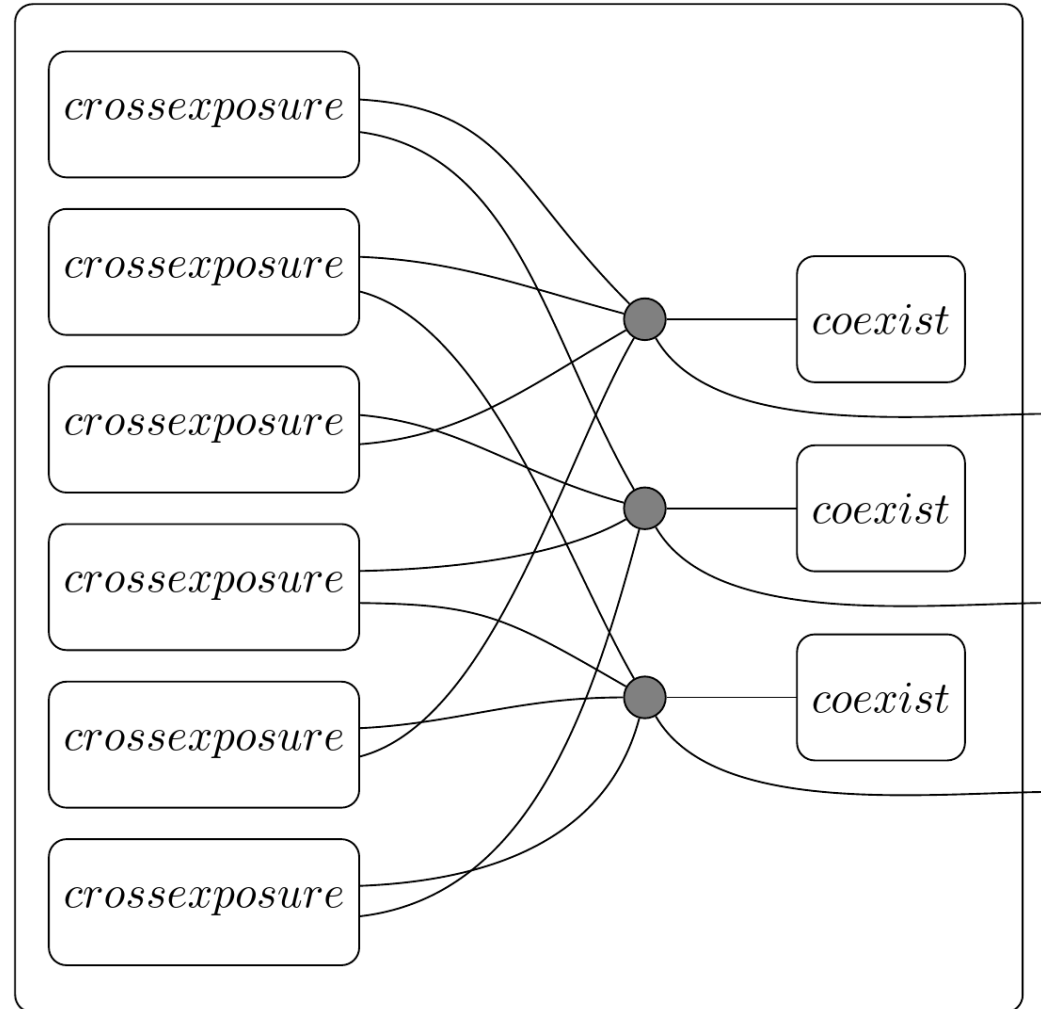
Petri Nets with Rates



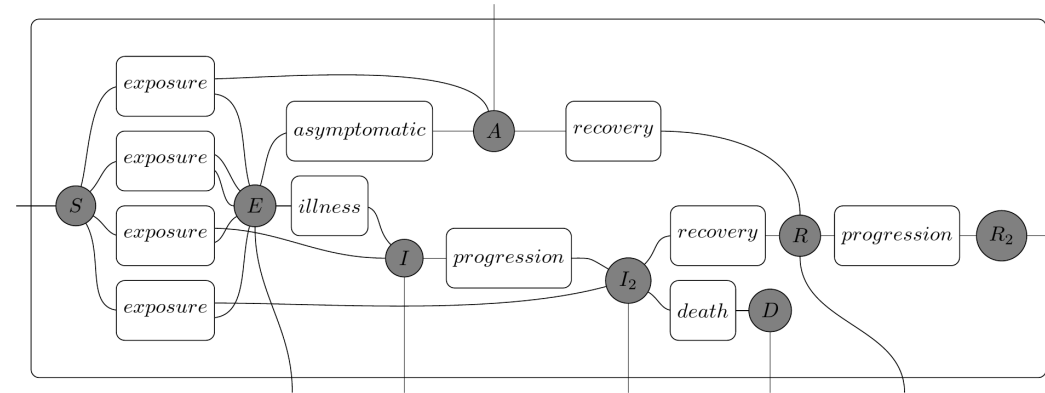
Undirected Wiring Diagrams



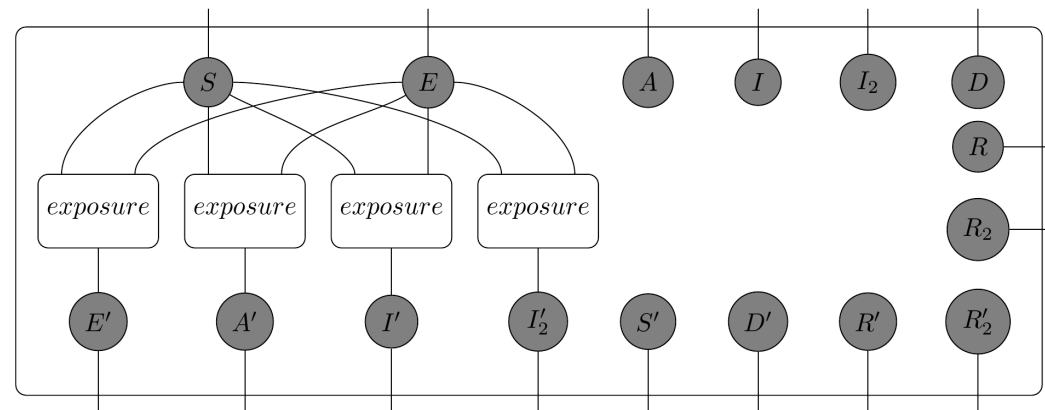
n -Generational COEXIST Model



Coexist:



Cross Exposure:



Relation Syntax

```
coexist = @relation (s::S, e::E, i::I, i2::I2, a::A, r::R, r2::R2, d::D) begin
    exposure(s, i, e)
    exposure(s, i2, e)
    exposure(s, a, e)
    exposure(s, e, e)
    illness(e, a)
    illness(e, i)
    progression(i, i2)
    death(i2, d)
    recovery(a, r)
    recovery(i2, r)
    progression(r, r2)
end
```

```
crossexposure = @relation (s::S, e::E, i::I, i2::I2, a::A, r::R, r2::R2, d::D,
                           s'::S, e'::E, i'::I, i2'::I2, a'::A, r'::R, r2'::R2, d'::D) begin
    exposure(s, i', e)
    exposure(s, i2', e)
    exposure(s, a', e)
    exposure(s, e', e)
end
```