A Cellular Automata Model of the Spread of HIV in a Community of Injection Drug Users

Automata 2007

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The Fields Institute

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Outline

1. Definition of the Problem
2. The Vancouver Downtown Eastside
3. Why use a CA model?
4. The Model
5. Modelling Scenarios
6. Results
7. Assumptions and Limitations
8. Conclusions
9. Future Work

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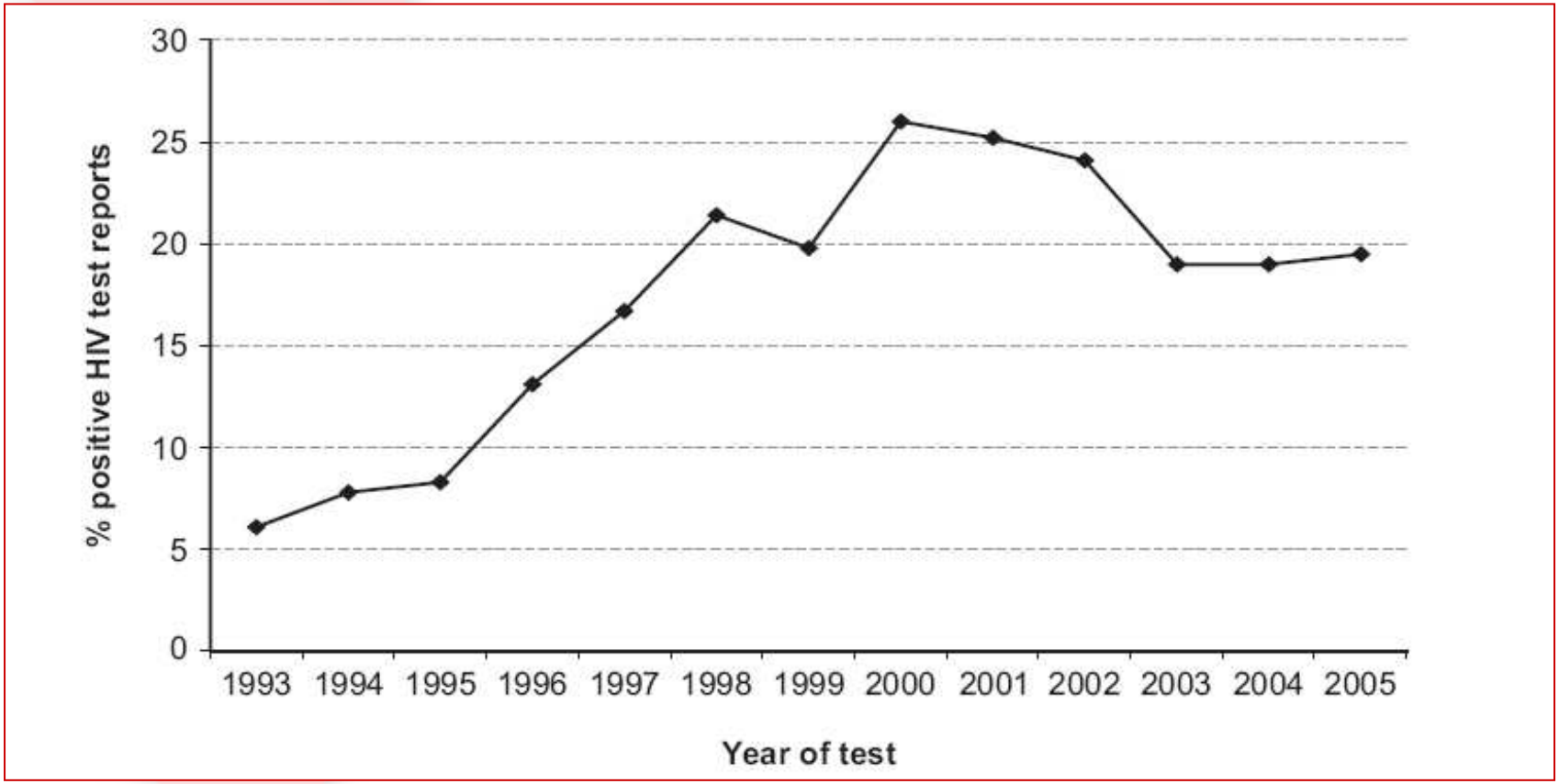
Definition of the Problem

- Injection Drug Users (IDU) are at high risk for contracting HIV
- Worldwide problem, including Canada
- Vancouver's Downtown Eastside (DTES) has among the worst HIV epidemic in North America
- Needle exchange programs seem to have contributed to declines but incidence remains high

Definition of the Problem

Proportion of positive HIV tests attributed to IDU in Canada (PHAC, 2006)



Definition of the Problem

- So, what drives the HIV epidemic?
- HIV transmission among IDU has at least two components:

  Biological and Mechanical Component

  à Efficiency of viral transmission through a contaminated needle

  Social Component

  à Social context leading to sharing of contaminated needles
- Need to understand the effects of social influence to understand the epidemic

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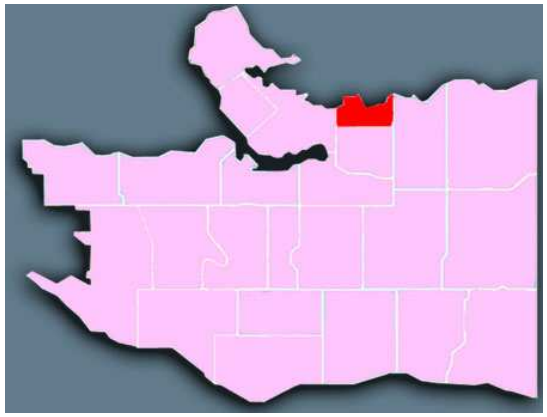
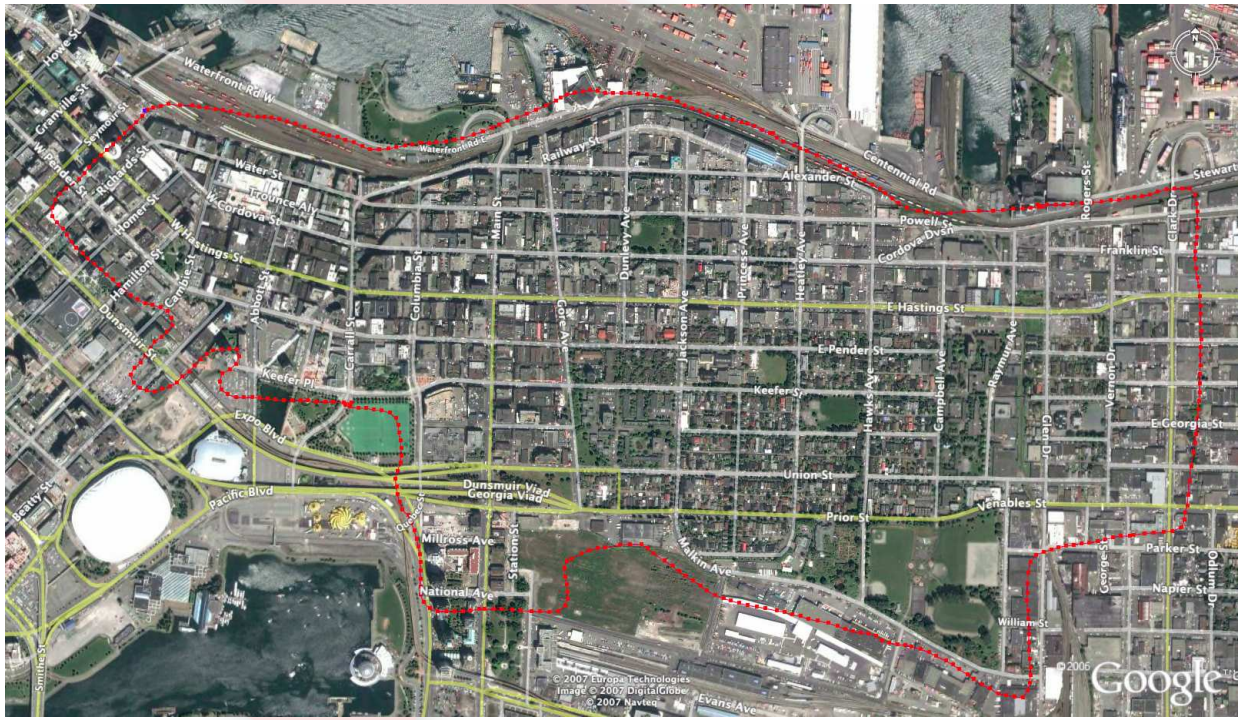
Vancouver Downtown Eastside

Total population ~ 17000





10 square block area

The poorest neighbourhood in Canada

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2000 homeless

24,000 IDUs in BC

8000 IDUs in Vancouver
5000 to 6000 in DTES

35% HIV positive

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Why use a CA model?

- Understand effect of micro-level interactions on macro-level process
- Specifically, effect of individual behaviour and interpersonal interaction on the HIV epidemic in the population
- Social interactions occur in a spatial context and CA can incorporate this

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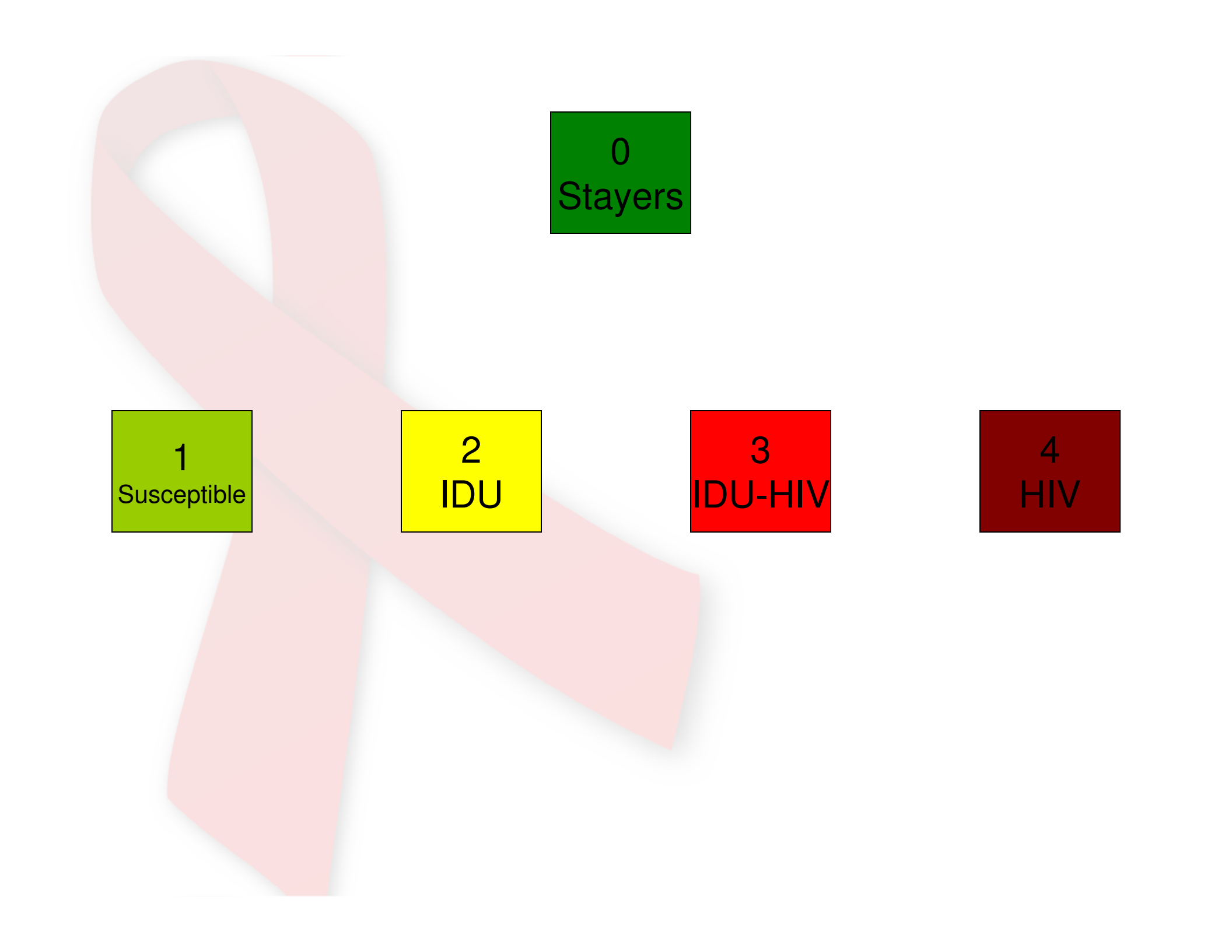
Agents

0. **Stayer** is someone who will never use drugs.
1. **Susceptible** is someone who does not currently use drugs via injection, but could become an IDU.
2. **IDU** is an injection drug user who does not carry the HIV virus.
3. **IDU-HIV** is an injection drug user who carries the HIV virus.
4. **HIV** is someone who contracted the HIV virus through injection drug use and then stopped the use of drugs.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Stayers
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IDU-HIV
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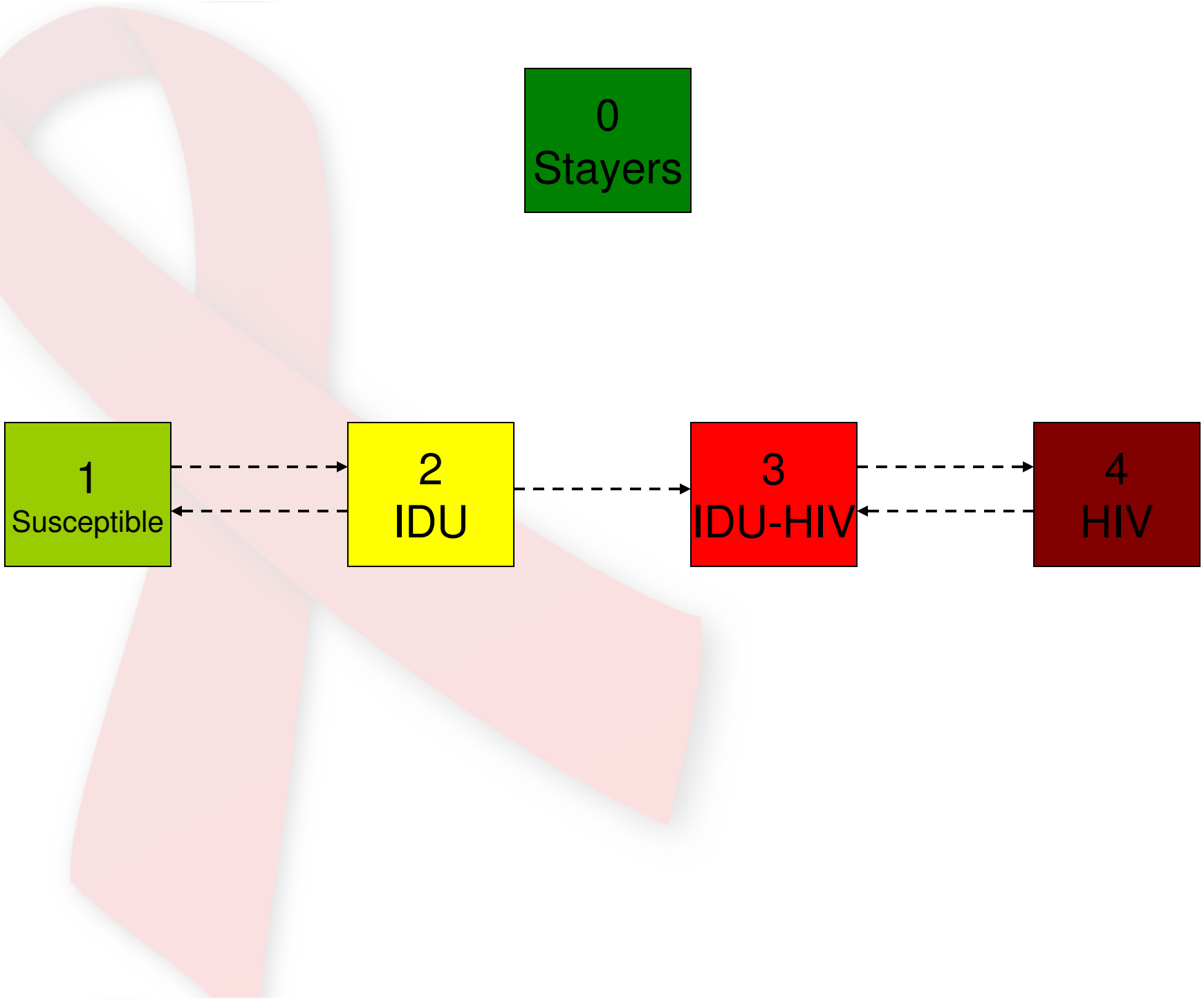
HIV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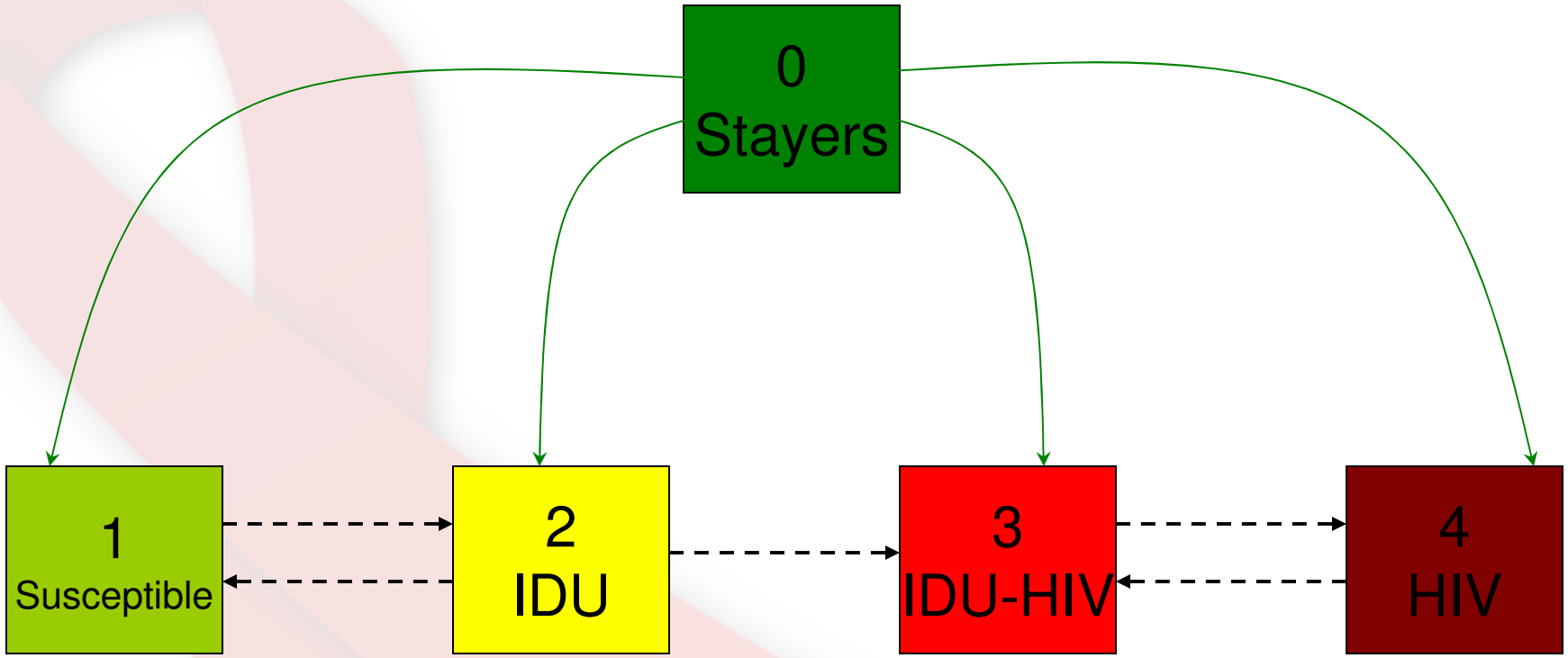
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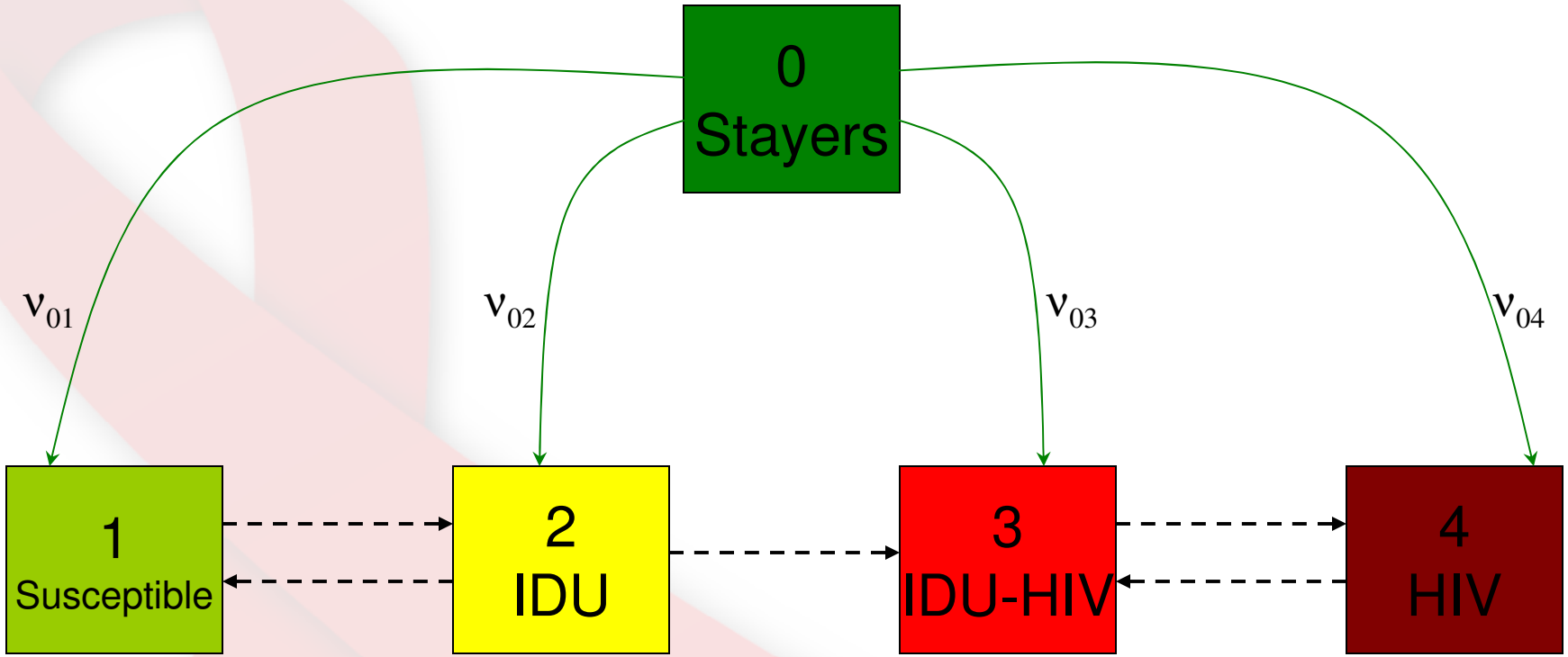
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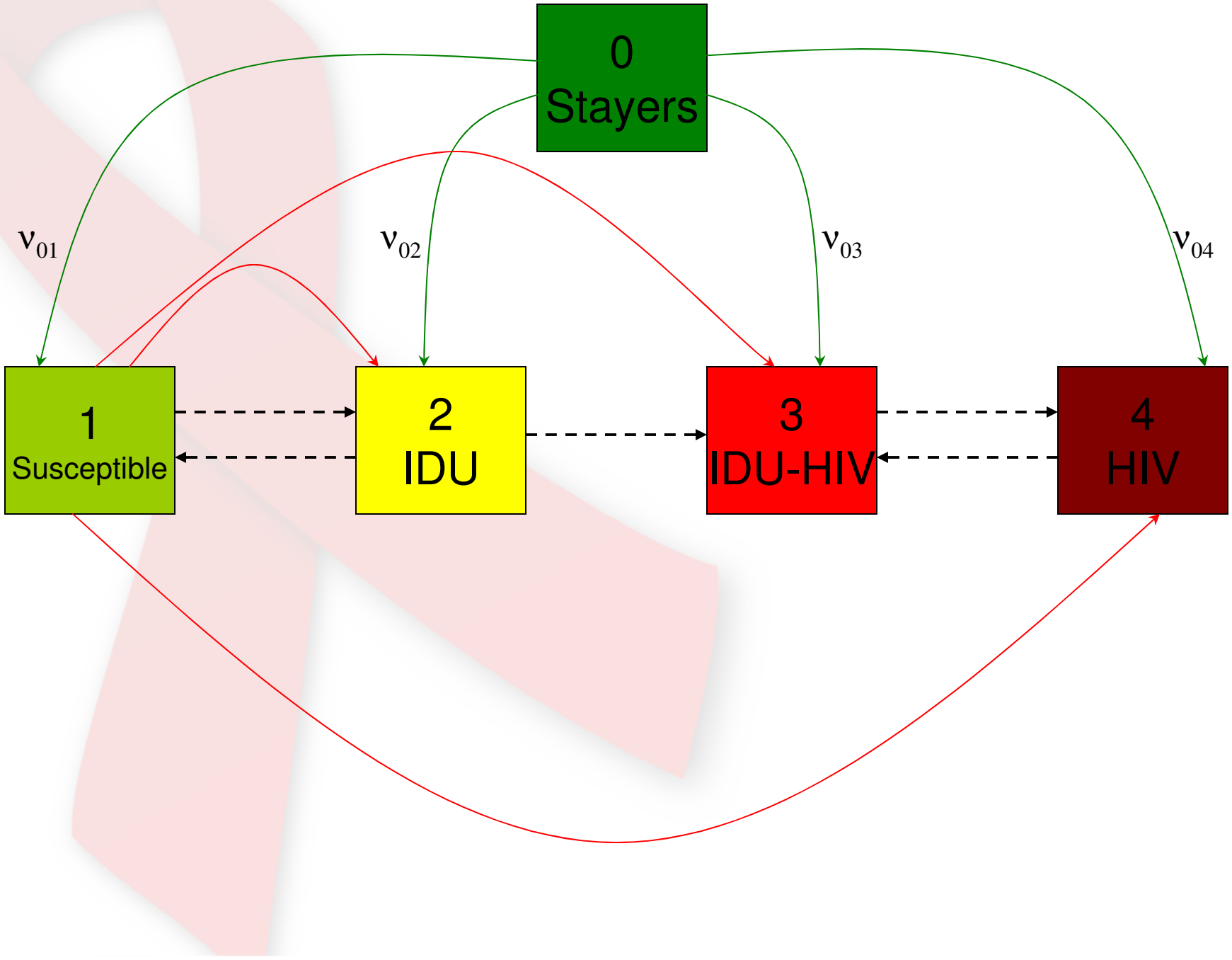
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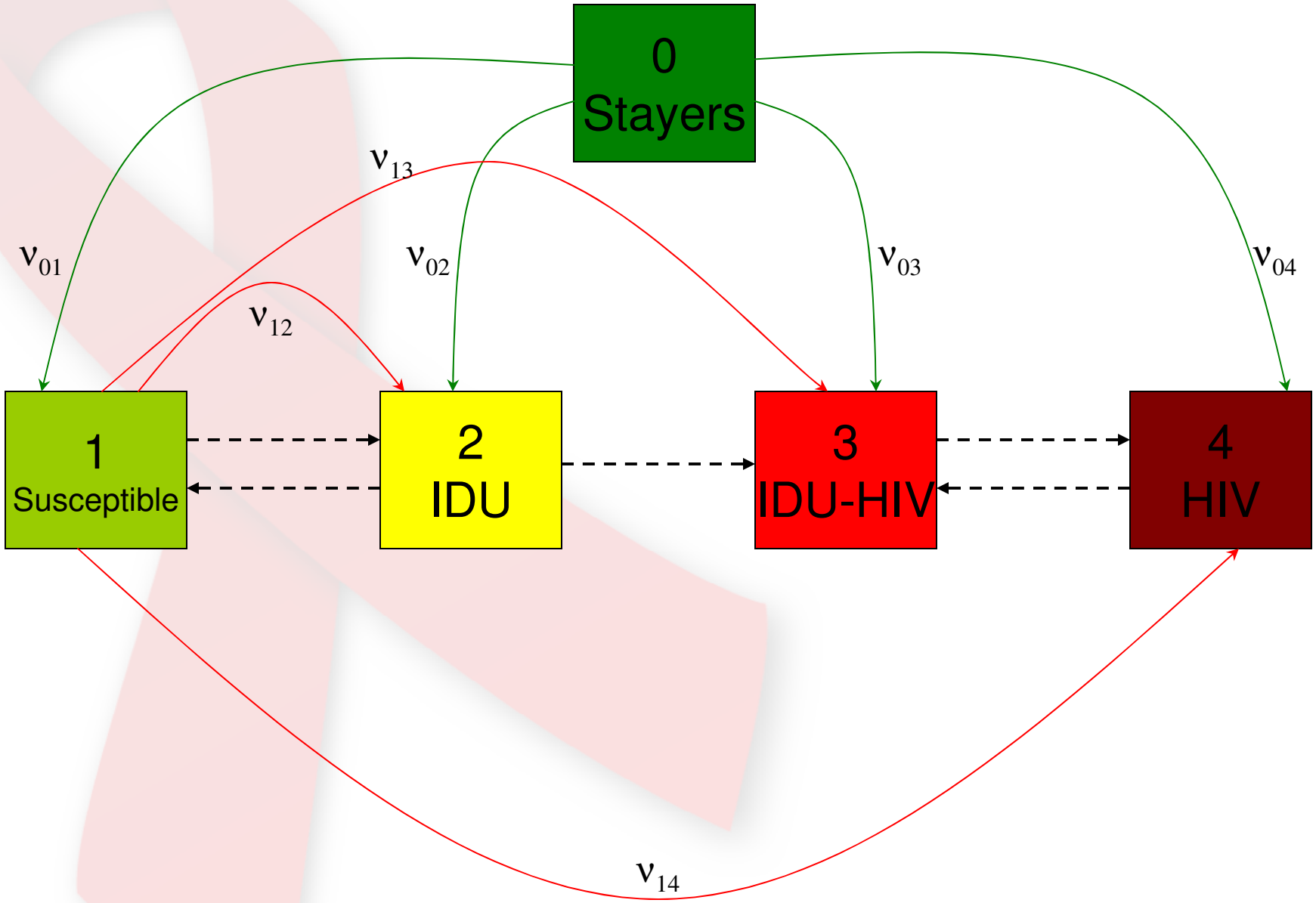
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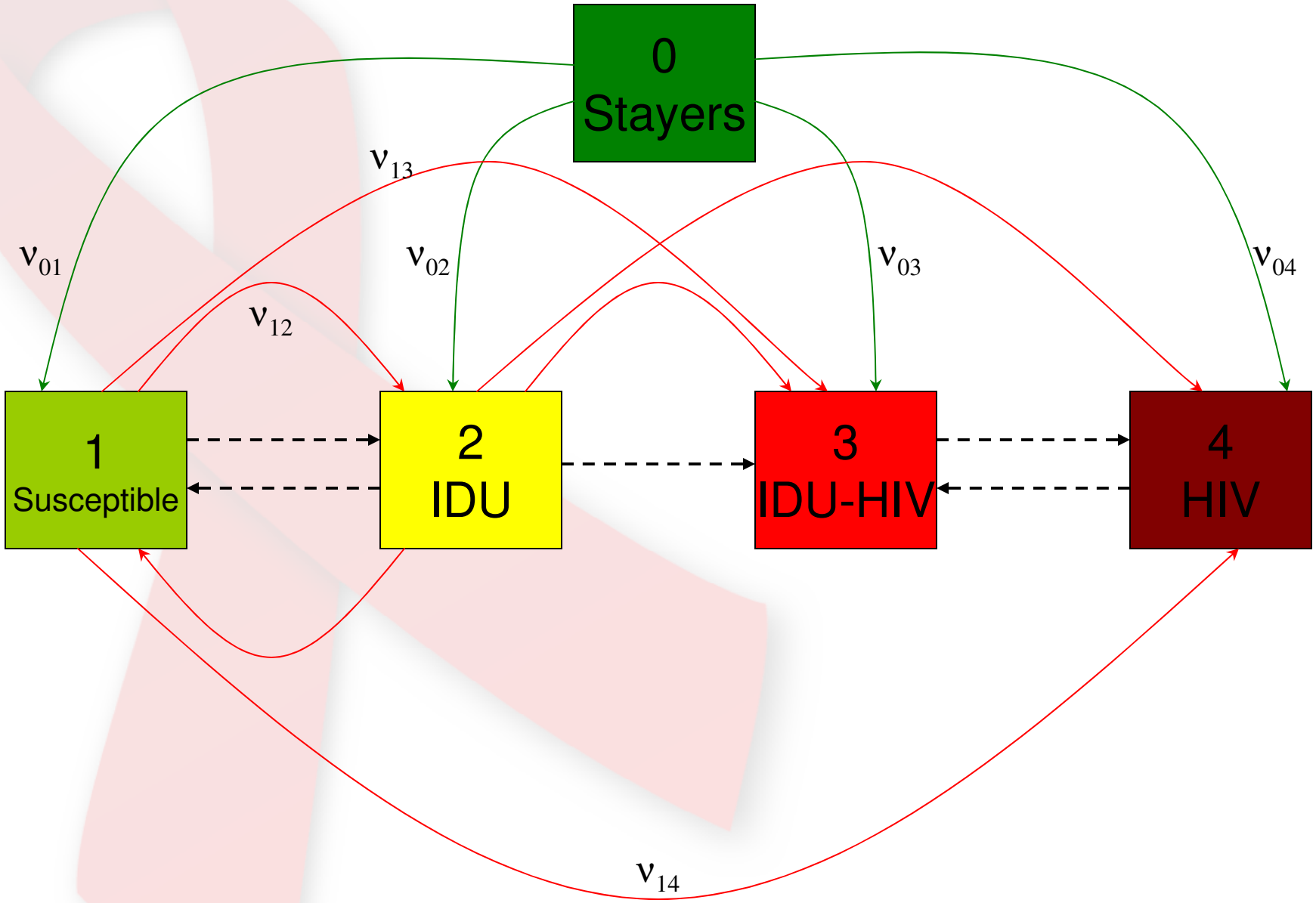
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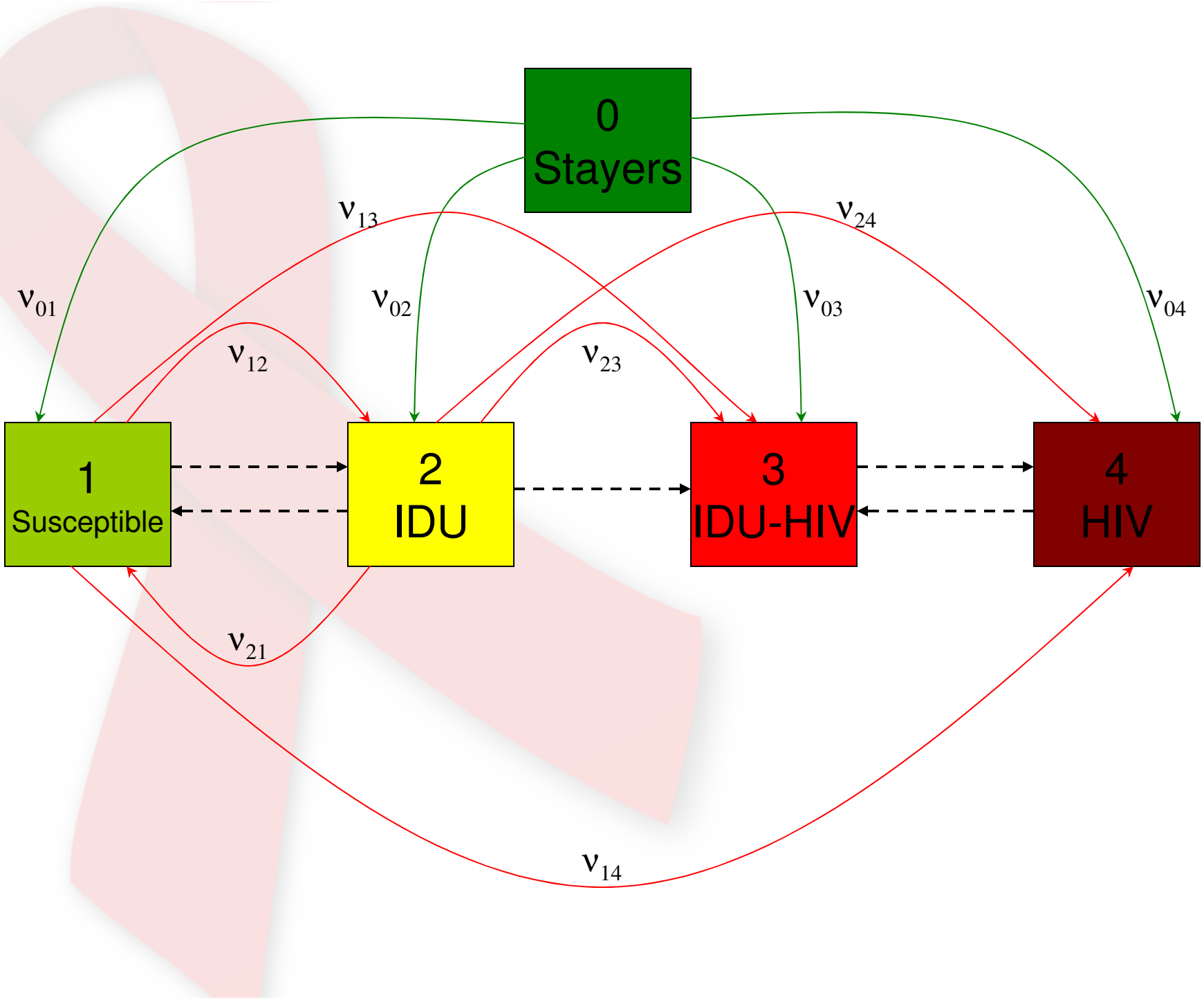
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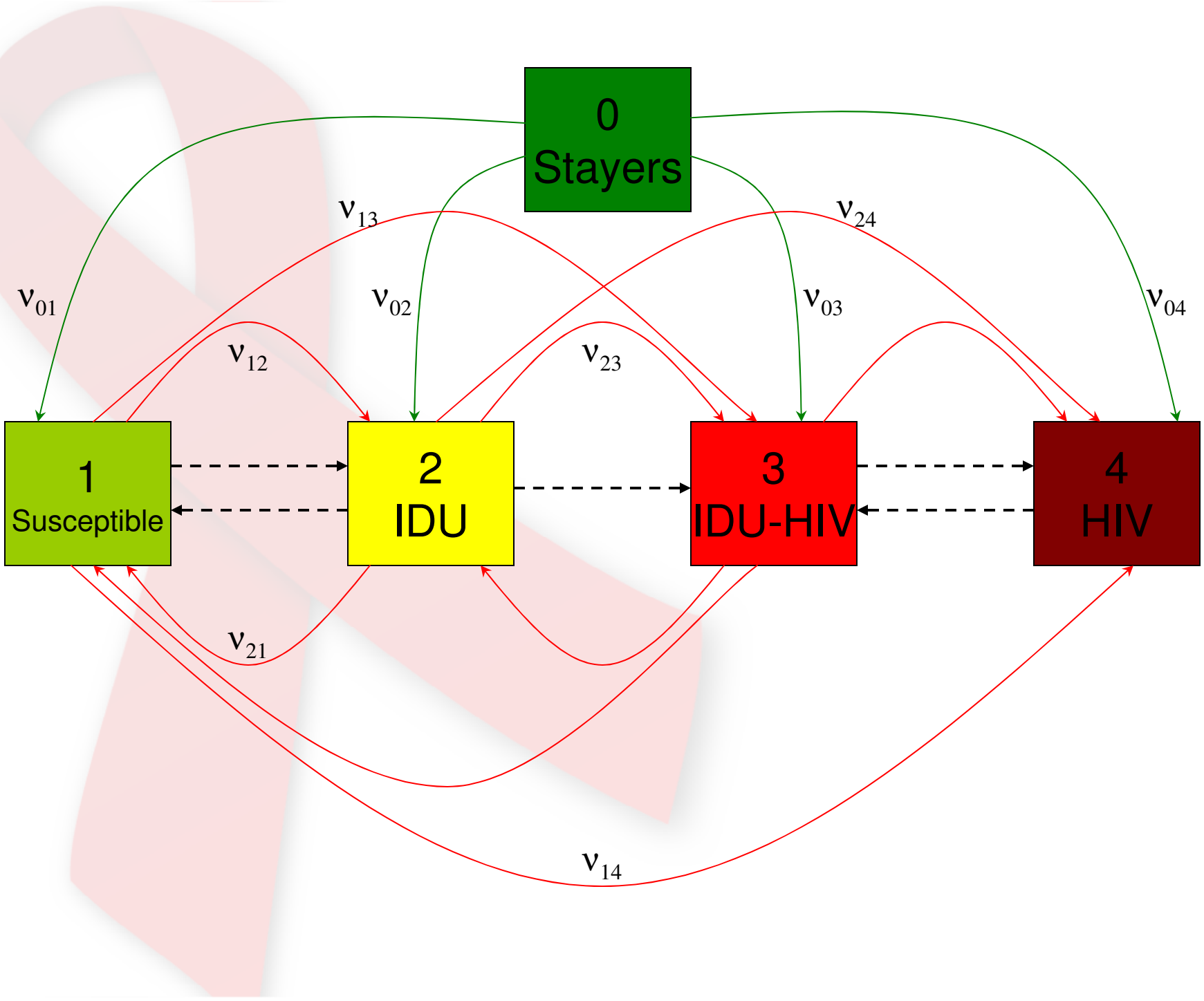
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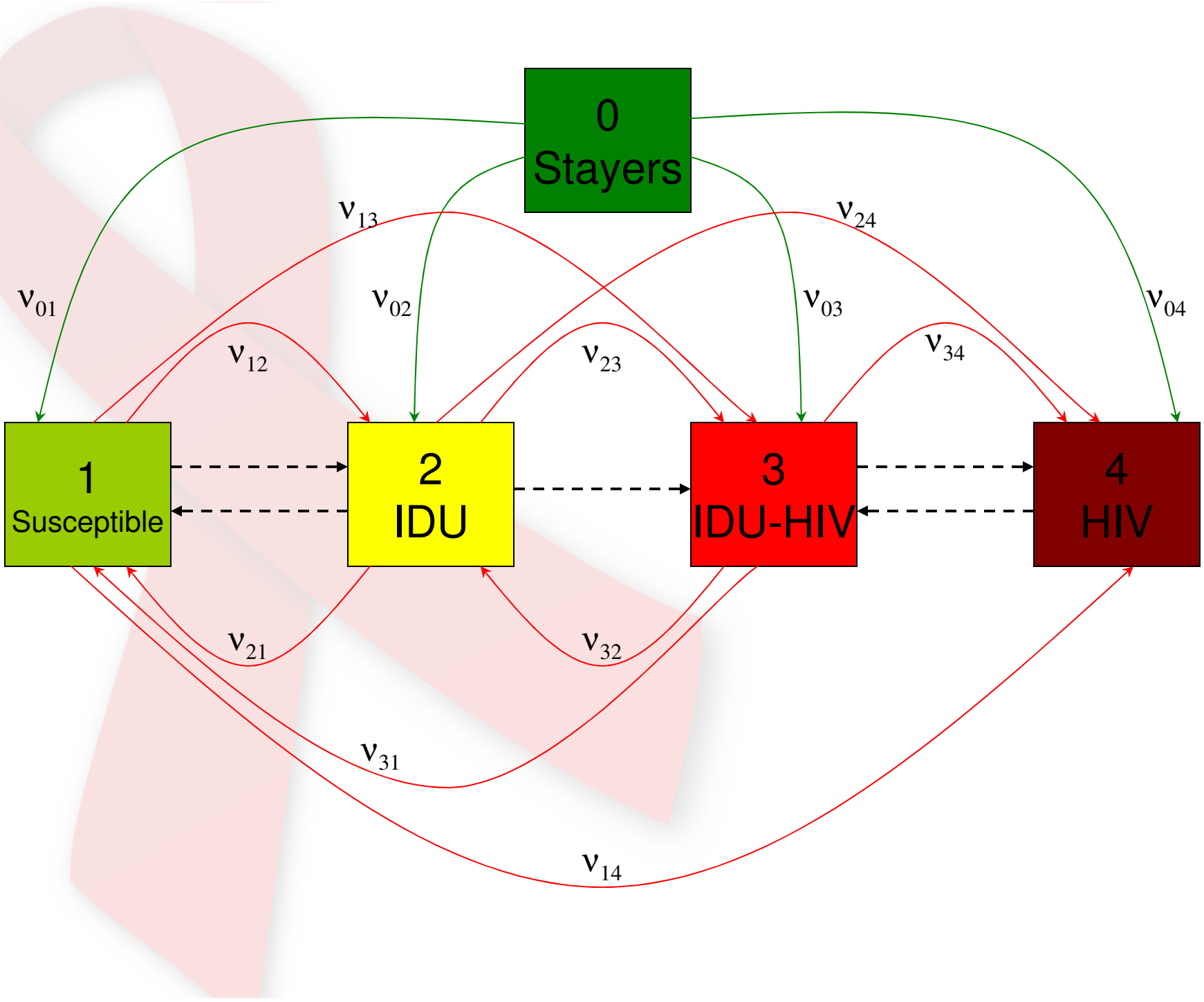
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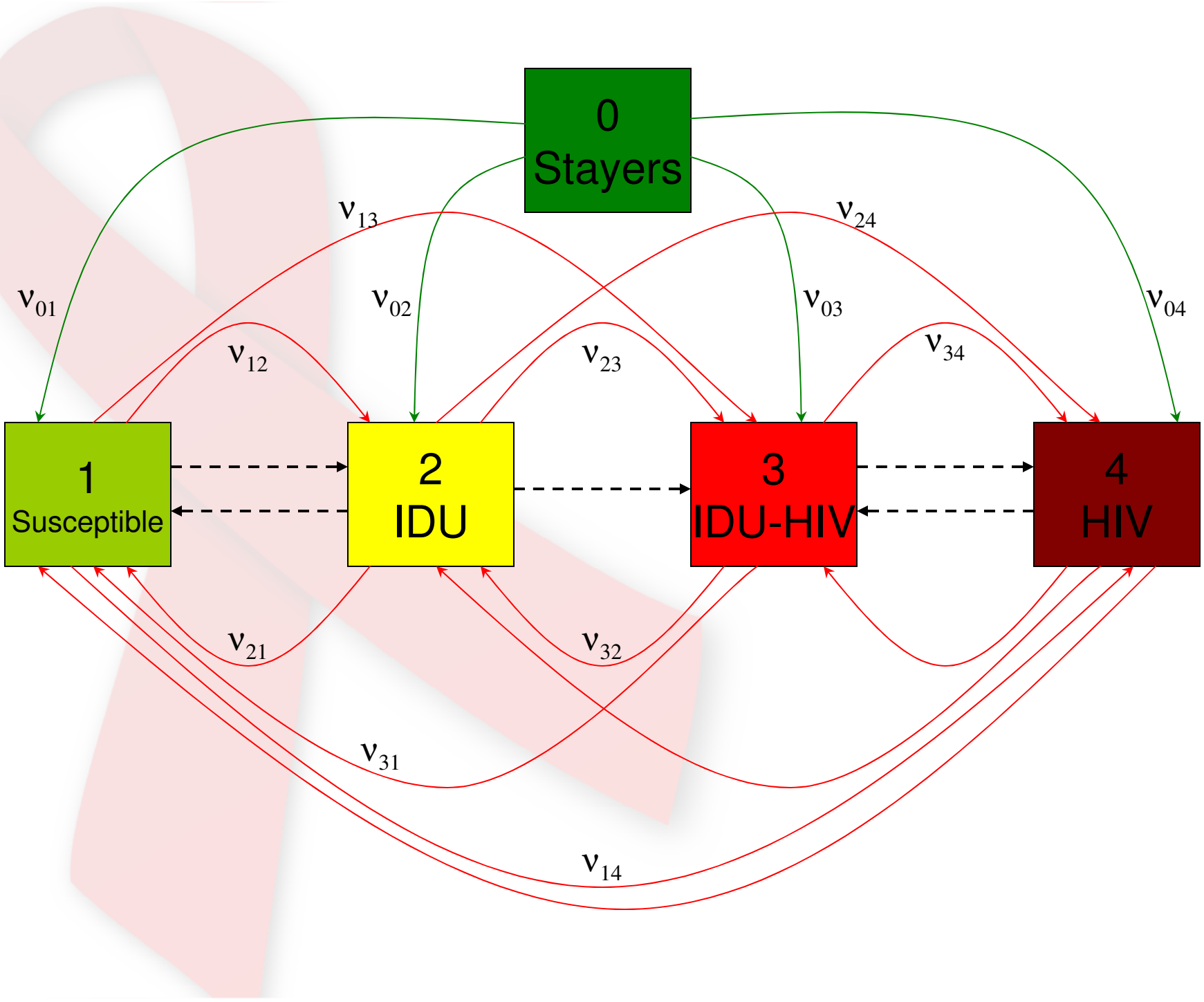
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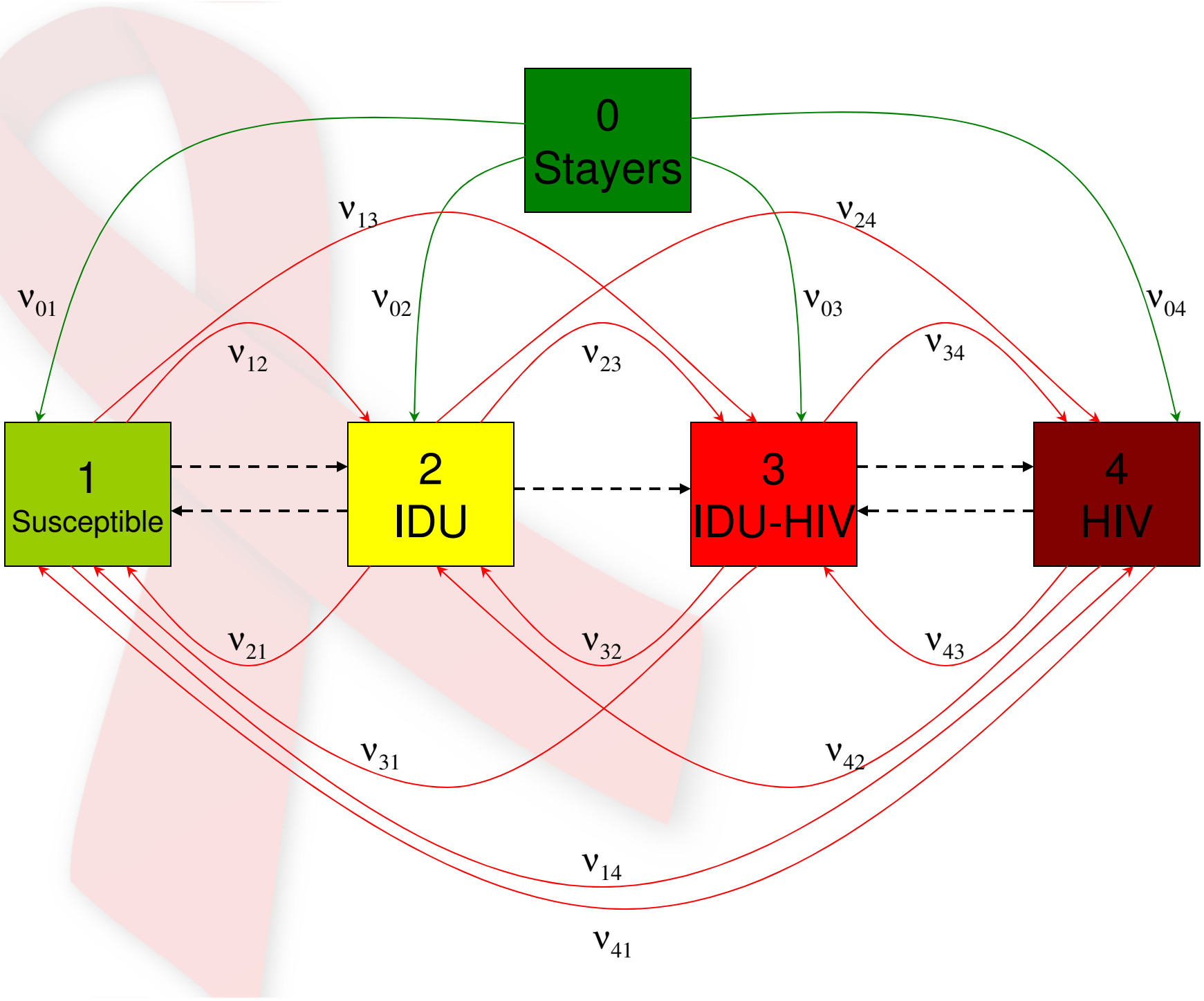
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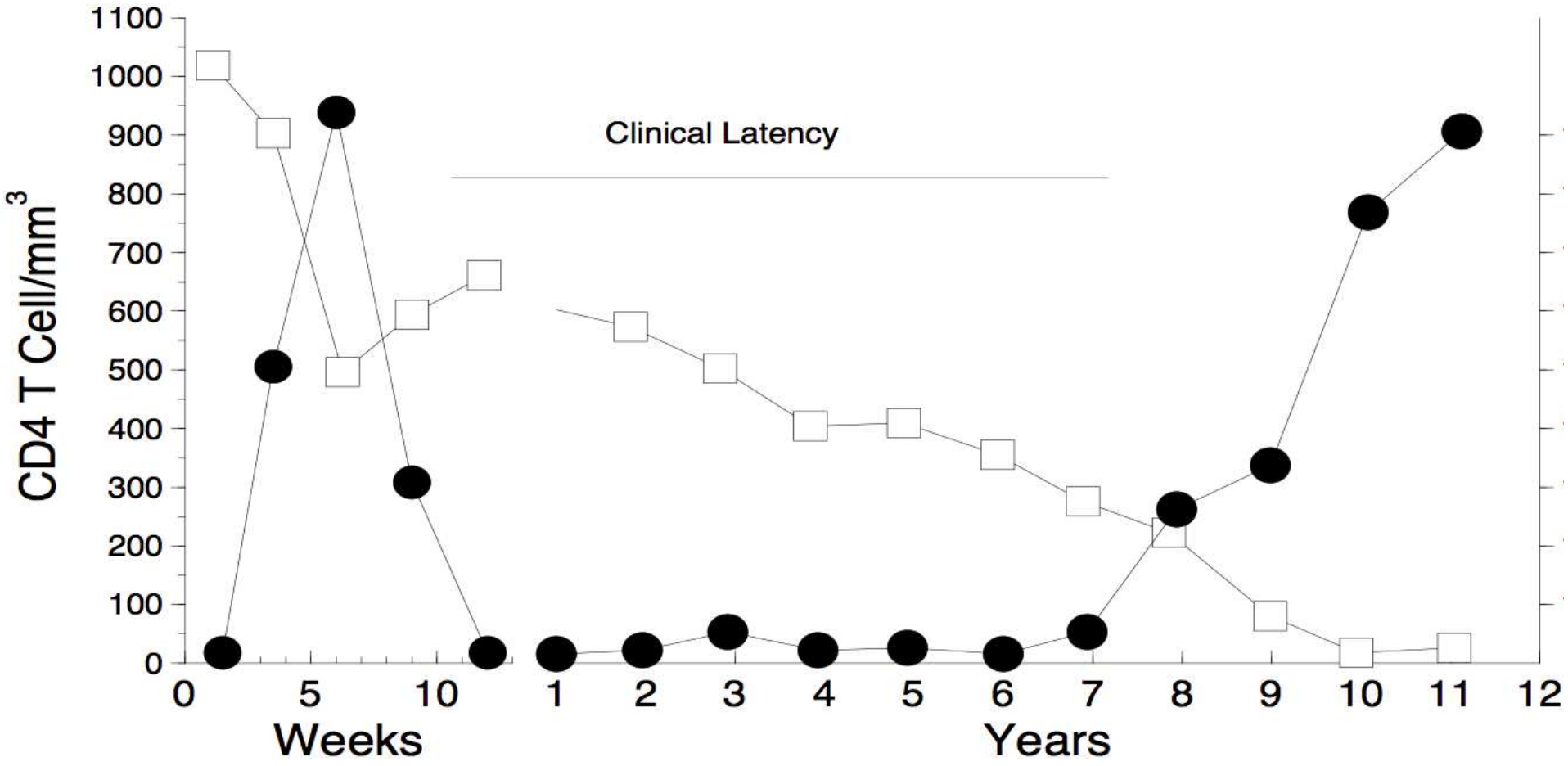
Viral Load Time Course



Social Counters

- A counter $C_i(t)$ records the influences of one's neighbours associated with each cell

$$C_1(t) = C_1(t - 1) + R_0 v_{01} + R_1 u_1 + R_2 v_{21} + R_3 v_{31} + R_4 v_{41}$$
$$C_2(t) = C_2(t - 1) + R_0 v_{02} + R_1 v_{12} + R_2 u_2 + R_3 v_{32} + R_4 v_{42}$$
$$C_3(t) = C_3(t - 1) + R_0 v_{03} + R_1 v_{13} + R_2 v_{23} + R_3 u_3 + R_4 v_{43}$$
$$C_4(t) = C_4(t - 1) + R_0 v_{04} + R_1 v_{14} + R_2 v_{24} + R_3 v_{34} + R_4 u_4$$

Where R_i is the number cells of type $i = 0,\ldots,4$ in a neighbourhood and u_i is the influence that a particular group has upon themselves

RULES

- **Update of a susceptible:**
  a) a susceptible dies after τ_1 time steps.
  b) if $C_1 \leq -1$ then the susceptible becomes an IDU.

- **Update of an IDU:**
  a) an IDU dies after τ_2 time steps.
  b) for each IDU-HIV in its neighbourhood the IDU has probability *p* of contracting the HIV virus and becoming an IDU-HIV for each contaminated needlee shared. If the HIV-IDU neighbour was infected ≤ 2 or ≥ 84 months ago, p is 0.5, otherwise p is 0.001.
  c) if the IDU does not contract HIV and $C_2 \geq 1$ then the IDU becomes a susceptible.

- **Update of an IDU-HIV:**
  a) an IDU-HIV dies after carrying the disease for τ_3 time steps.
  b) if the IDU-HIV does not die and $C_3 \geq 1$ then the IDU-HIV becomes an HIV.

- **Update of an HIV:**
  a) an HIV dies after carrying the disease for τ_4 time steps.
  b) if the HIV does not die and $C_4 \leq -1$ then the HIV becomes an IDU-HIV.

RULES

- **Update of a susceptible:**
  a) a susceptible dies after τ_1 time steps.
  b) if $C_1 \leq -1$ then the susceptible becomes an IDU.

- **Update of an IDU:**
  a) an IDU dies after τ_2 time steps.
  b) for each IDU-HIV in its neighbourhood the IDU has probability *p* of contracting the HIV virus and becoming an IDU-HIV for each contaminated needlee shared. If the HIV-IDU neighbour was infected ≤ 2 or ≥ 84 months ago, p is 0.5, otherwise p is 0.001.
  c) if the IDU does not contract HIV and $C_2 \geq 1$ then the IDU becomes a susceptible.

- **Update of an IDU-HIV:**
  a) an IDU-HIV dies after carrying the disease for τ_3 time steps.
  b) if the IDU-HIV does not die and $C_3 \geq 1$ then the IDU-HIV becomes an HIV.

- **Update of an HIV:**
  a) an HIV dies after carrying the disease for τ_4 time steps.
  b) if the HIV does not die and $C_4 \leq -1$ then the HIV becomes an IDU-HIV.

RULES

- **Update of a susceptible:**
  a) a susceptible dies after τ_1 time steps.
  b) if $C_1 \leq -1$ then the susceptible becomes an IDU.

- **Update of an IDU:**
  a) an IDU dies after τ_2 time steps.
  b) for each IDU-HIV in its neighbourhood the IDU has probability *p* of contracting the HIV virus and becoming an IDU-HIV for each contaminated needlee shared. If the HIV-IDU neighbour was infected ≤ 2 or ≥ 84 months ago, p is 0.5, otherwise p is 0.001.
  c) if the IDU does not contract HIV and $C_2 \geq 1$ then the IDU becomes a susceptible.

- **Update of an IDU-HIV:**
  a) an IDU-HIV dies after carrying the disease for τ_3 time steps.
  b) if the IDU-HIV does not die and $C_3 \geq 1$ then the IDU-HIV becomes an HIV.

- **Update of an HIV:**
  a) an HIV dies after carrying the disease for τ_4 time steps.
  b) if the HIV does not die and $C_4 \leq -1$ then the HIV becomes an IDU-HIV.

RULES

- **Update of a susceptible:**
  a) a susceptible dies after τ_1 time steps.
  b) if $C_1 \leq -1$ then the susceptible becomes an IDU.

- **Update of an IDU:**
  a) an IDU dies after τ_2 time steps.
  b) for each IDU-HIV in its neighbourhood the IDU has probability *p* of contracting the HIV virus and becoming an IDU-HIV for each contaminated needlee shared. If the HIV-IDU neighbour was infected ≤ 2 or ≥ 84 months ago, p is 0.5, otherwise p is 0.001.
  c) if the IDU does not contract HIV and $C_2 \geq 1$ then the IDU becomes a susceptible.

- **Update of an IDU-HIV:**
  a) an IDU-HIV dies after carrying the disease for τ_3 time steps.
  b) if the IDU-HIV does not die and $C_3 \geq 1$ then the IDU-HIV becomes an HIV.

- **Update of an HIV:**
  a) an HIV dies after carrying the disease for τ_4 time steps.
  b) if the HIV does not die and $C_4 \leq -1$ then the HIV becomes an IDU-HIV.

RULES

- **Update of a susceptible:**
  a) a susceptible dies after τ_1 time steps.
  b) if $C_1 \leq -1$ then the susceptible becomes an IDU.

- **Update of an IDU:**
  a) an IDU dies after τ_2 time steps.
  b) for each IDU-HIV in its neighbourhood the IDU has probability *p* of contracting the HIV virus and becoming an IDU-HIV for each contaminated needlee shared. If the HIV-IDU neighbour was infected ≤ 2 or ≥ 84 months ago, p is 0.5, otherwise p is 0.001.
  c) if the IDU does not contract HIV and $C_2 \geq 1$ then the IDU becomes a susceptible.

- **Update of an IDU-HIV:**
  a) an IDU-HIV dies after carrying the disease for τ_3 time steps.
  b) if the IDU-HIV does not die and $C_3 \geq 1$ then the IDU-HIV becomes an HIV.

- **Update of an HIV:**
  a) an HIV dies after carrying the disease for τ_4 time steps.
  b) if the HIV does not die and $C_4 \leq -1$ then the HIV becomes an IDU-HIV.

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Modelling Scenarios

1. **No Social Influence Scenario**

   HIV transmission depends only on initial numbers of IDU, IDU-HIV and transmission probability.

2. **Peer Pressure Scenario**

   IDU and IDU-HIV exert peer pressure on everyone to use drugs (and share needles), while Stayers exert strong pressure on all to discontinue drug use. Susceptibles and HIV exert a week positive influence on everyone.

3. **Pessimistic Scenario**

   HIV and IDU-HIV exert pressure on everyone to use drugs, while Stayers discourage everyone from using drugs. In this case Susceptibles and HIV exert a week negative influence (Auld, 2003)

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Parameters Estimation

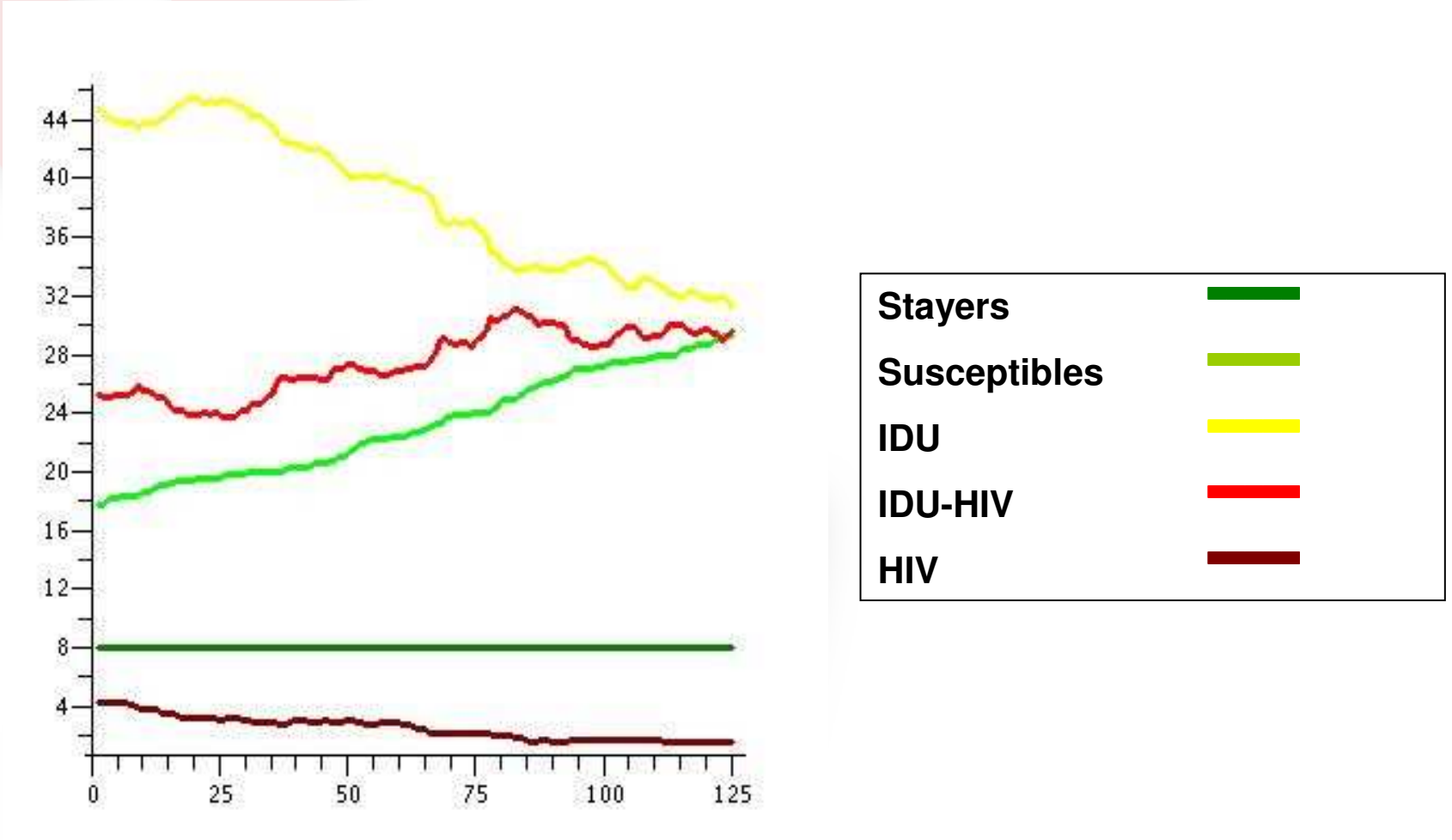
Parameters	Variation Range
% of IDUs sharing needles	20 - 40
# of sharing needles per day	0.03 - 0.06
Life expectancy for IDU-HIV and HIV	4 - 8 years

PHAC Epi Update 2006

Social Interactions

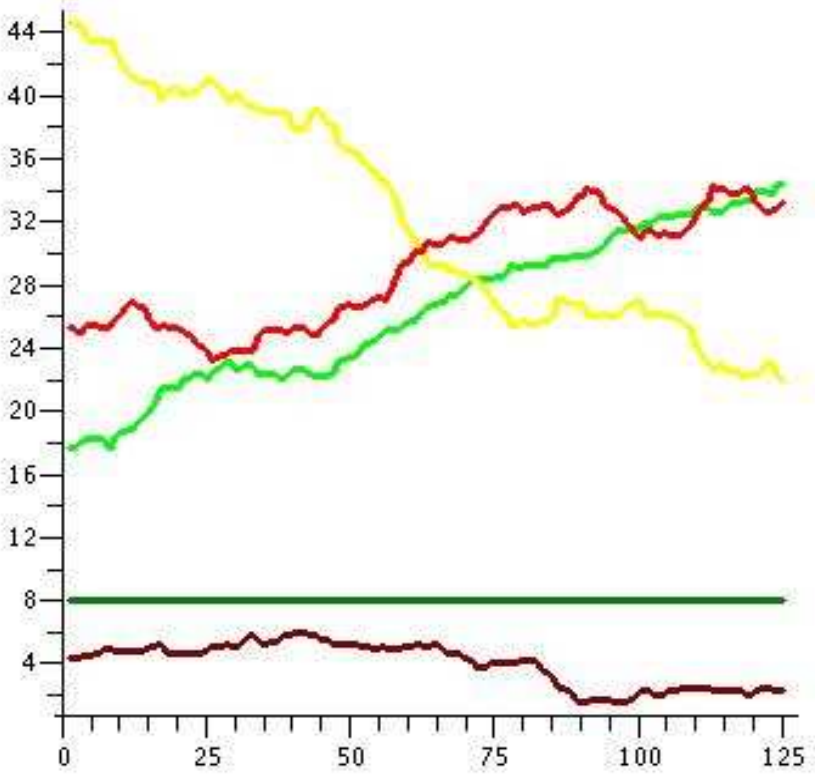
Agents	No Influence	Peer Pressure	Pessimistic
0 (Stayers)	0	1/30	1/30
1 (Susceptible)	0	1/300	-1/300
2 (IDU)	0	-1/150	-1/150
3 (IDU-HIV)	0	-1/150	-1/150
4 (HIV)	0	1/300	-1/300

Results

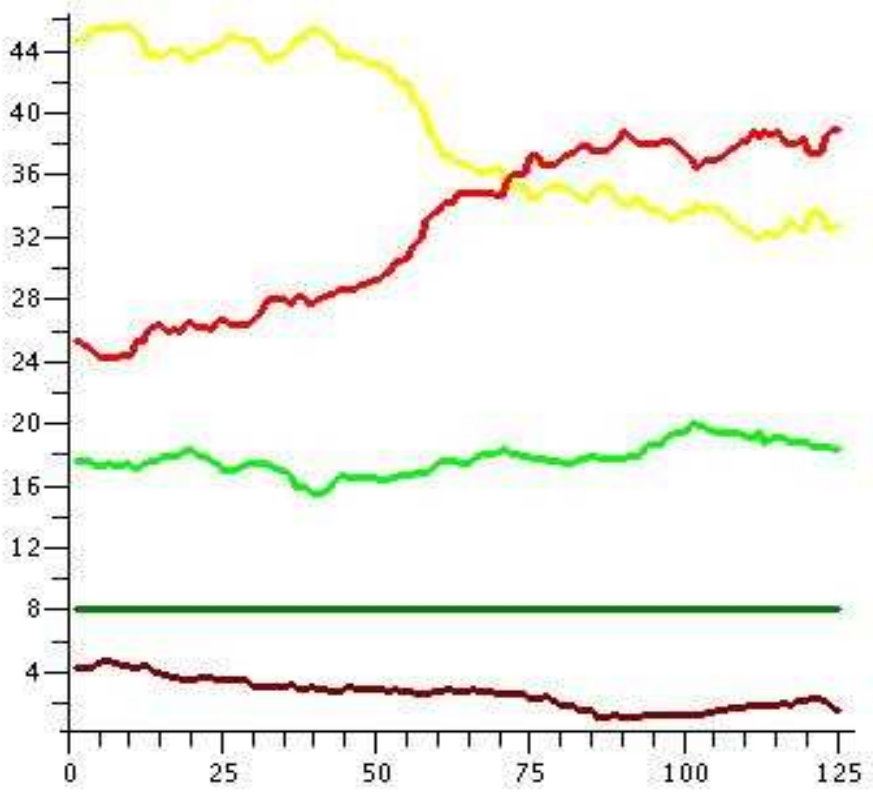


No Social Influence Scenario

Results



Peer Pressure Scenario



Pessimistic Scenario

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Assumptions and Limitations

- Homogeneity of the population regarding risk behaviour
- Constant population size
- No distinction made between drug use and needle-sharing behaviour

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Conclusions

- Without social influence, epidemic is stable
- With social influence, increase in number of HIV infections
- Pessimistic attitudes had a stronger effect than peer pressure

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Future Work

- Calibrate model to data from DTES and other settings
- Incorporate needle-sharing behaviour at the micro level
- Incorporate concurrent risky IDU and sexual behaviour
- Incorporate spatial landmarks

Acknowledgements

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MITACS

and

The Fields Institute