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The dynamics of computer virus infection

A System dynamics perspective

Any system or program, however complicated, if looked at in exactly the right way, will become even more complicated.

Anderson's Law

The dynamics of computer virus infection

A System dynamics perpective

Introduction

The goal of this survey is to study some key parameters that may influence the propagation of a computer virus. Computer viruses are becoming more and more popular in our interconnected society. In 2001, TrueSecure® Corporation has made a survey on 300 organizations with more than 500 PCs each. The result of this survey shows that this group of 300 organizations had 1,182,634 encounters on 666,327 machines during a period of 20 months, which was from January 2000 to August 2001. This translates to 113 encounters per 1,000 machines per month over the entire period. According to another study made by the same organization, the global infection rates calculated their surveys of 1996 through 2001 continued a significant annual growth rate of approximately 20 encounters per month per 1,000 PCs for each year in that period.

The consequences of computer viruses may be very costly for companies. It is estimated that the average company might find cost between \$50,000 and \$500,000 in total ramification (both soft and hard cost) for virus disasters.

In their survey, 90 percent of the respondents reported protection for more than 90 percent of their PCs with anti-virus products. About 90 percent stated that 100 percent of their PCs were protected. Most PCs (about 71 percent) were reported to be protected by full-time automatic anti-virus protection.

Based on the SIR Model (a model of infectious disease), we will try to find out which are the key parameters that may influence virus propagation. We will show, based on our model that diversification may be the best way to prevent wide spread of computer virus.

Presentation of the model

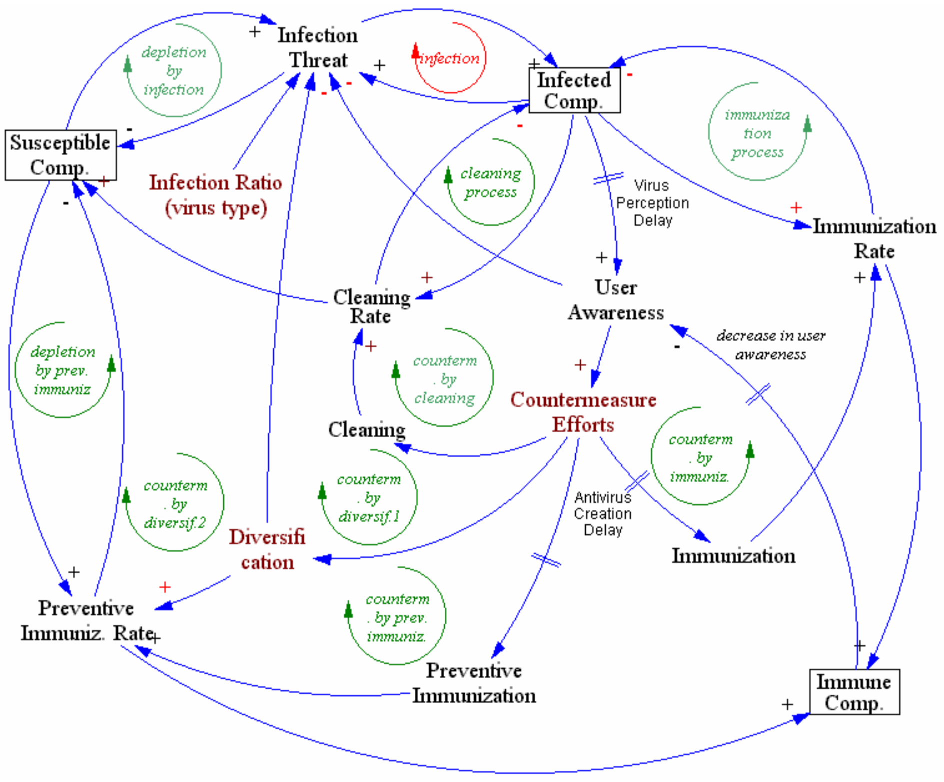
Our model is based of the SIR model which is a simple model of infectious disease. We choose the SIR model because computer viruses are somehow related to biological viruses in the sense that they need a host in order to survive. If an infected host, come into contact with a "clean" host, the clean host may become infected also. But contrary to biological virus, it is not possible for an infected host to develop a resistance by itself. A machine with anti-virus program may become immune to old known viruses but not to new ones.

In our study, we consider the population of computer to be fixed during the simulation. This means that there is no new computer coming in when we have started the simulation.

1. Case study for one computer Virus

In this section, we will study the special case where the system deals with only one computer virus. We will try to find out the different parameters that may prevent propagation.

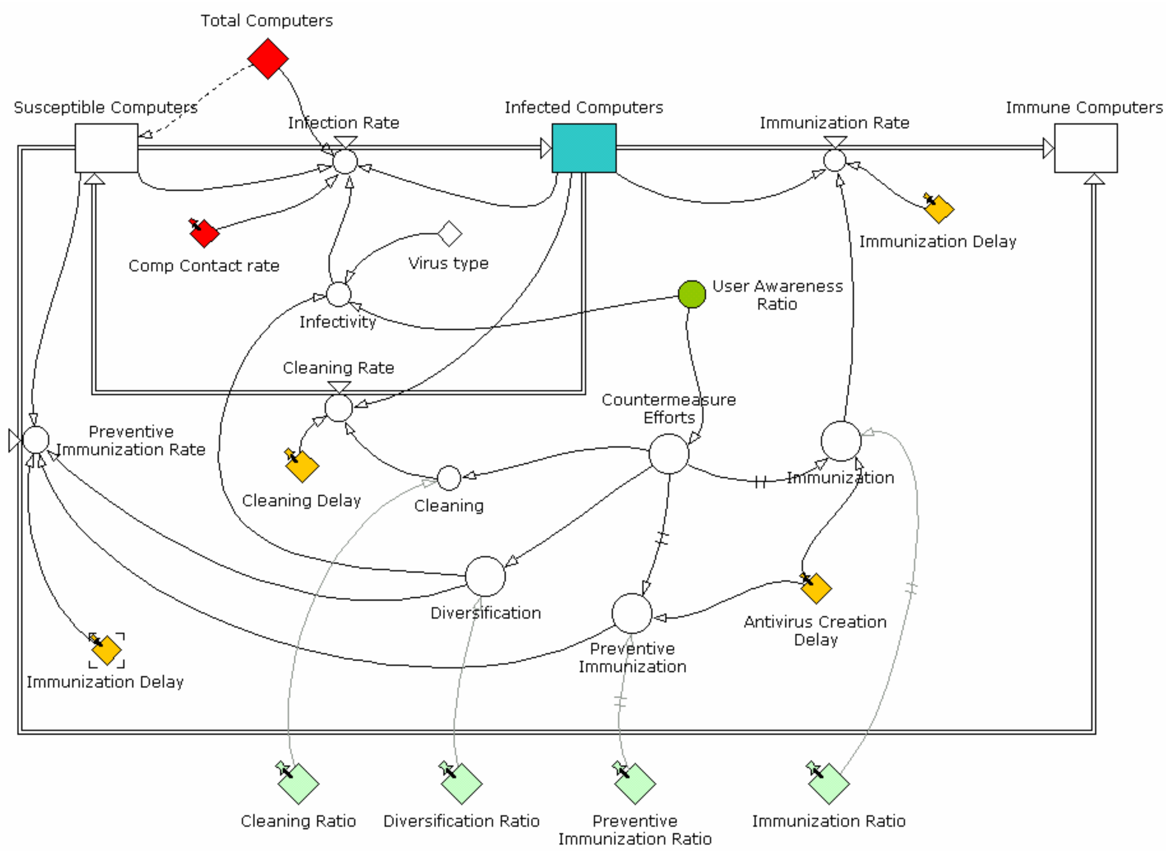
Casual Loop Diagram for the main model



- **Susceptible Comp.:** Susceptible computers that can be infected by the virus.
- **Infected Comp. :** Computers that are infected by the virus
- **Immune Comp.:** Computers that are immune to the virus. In the case of one virus, a computer can be immune by installing an anti-virus, since there will be no new virus that can affect this machine again. But as we will see it, this hypothesis does not work in the general case where new viruses are coming in the system.
- **User Awareness:** Describes how much the users are aware of the threat
- **Countermeasure Efforts:** Describe the measures that are taken in order to fight the threat. The different measures considered in this study are: cleaning the computer without installing an anti-virus program, installing an anti-virus program that will result in an immunization of the computer and will clean it at the same time, and the finally diversification. The immunization can be preventive or curative. In the first case, users will install an anti-virus program before getting infected.

We can see that we will have three stocks for the computer. One stock will consist of those that are susceptible to be infected, one of infected and the last one will consist of those that are immune. The infection rate, the immunization rate and the preventive immunization rate are the main flows controlling those stocks. But as we can see in the diagram, the user awareness will play in important role in fighting back the threat.

Stock and Flow diagram for the main model



In this diagram we have 3 stocks which are represented by: *susceptible computers, infected computers, immune computers.* We have 4 flows represented by: *infection rate, immunization rate, cleaning rate, preventive immunization rate.*

The *user awareness ratio* is represented in the Stock and Flow diagram below. This diagram describes how we implement the *user awareness.*

- **Susceptible Computers:** Computers that can be infected by a virus.
- **Infected Computers:** Computers that are infected by a virus.
- **Immune Computers:** Computers which are immune.

During the simulation, there are no new computers coming into the system. The total number of computers is constant.

Total Computers = Susceptible Computers + Infected Computers + Immune Computers

- **Immunization Rate:** The rate at which computers become immune.

*'Infected Computers'*Immunization/'Immunization Delay'*

- **Immunization Delay:** The average time to immunize one computer.

- **Infection Rate:** Infection rate of the virus. It is based on the SIR model. We have:

IF ('Susceptible Computers'>0) 'Susceptible Computers' *Infectivity*'Comp Contact rate'*'Infected Computers' / 'Total Computers' ELSE 0

- **Infectivity:** This parameter describes the efficiency of the virus. When an infected computer come into contact with another one, there is a probability of infecting the new machine.

'Virus type'(1-'User Awareness Ratio') +(1-'Virus type')*(1-Diversification)*

- **Virus Type:** Take into account that the *Infectivity* of a virus may depend on the *User Awareness* (mail virus for example) while for others *Diversification* may play be an important factor (virus that exploit security holes for example).

- **Comp Contact Rate:** Describe how many computers contacted per computer per time period.

- **Countermeasure Efforts:** the different option that a user can take to fight a threat. In this example, countermeasure is added for clarity because we have:

'Countermeasure Efforts' = 'User Awareness Ratio'

- **Cleaning Rate:** The rate at which the computers are cleaned (the virus is remove but the computer can still be infected by the same virus again).

*'Infected Computers'*Cleaning/'Cleaning Delay'*

- **Cleaning Delay:** Average time to clean a machine.

- **Cleaning:** the percentage of the users that will use cleaning as a countermeasure.

- **Diversification:** The percentage of users that choose to use another program, or a different system.

- **Preventive Immunization Rate:** The rate at which users immune their machine. Only aware users will decide to immune their machine.

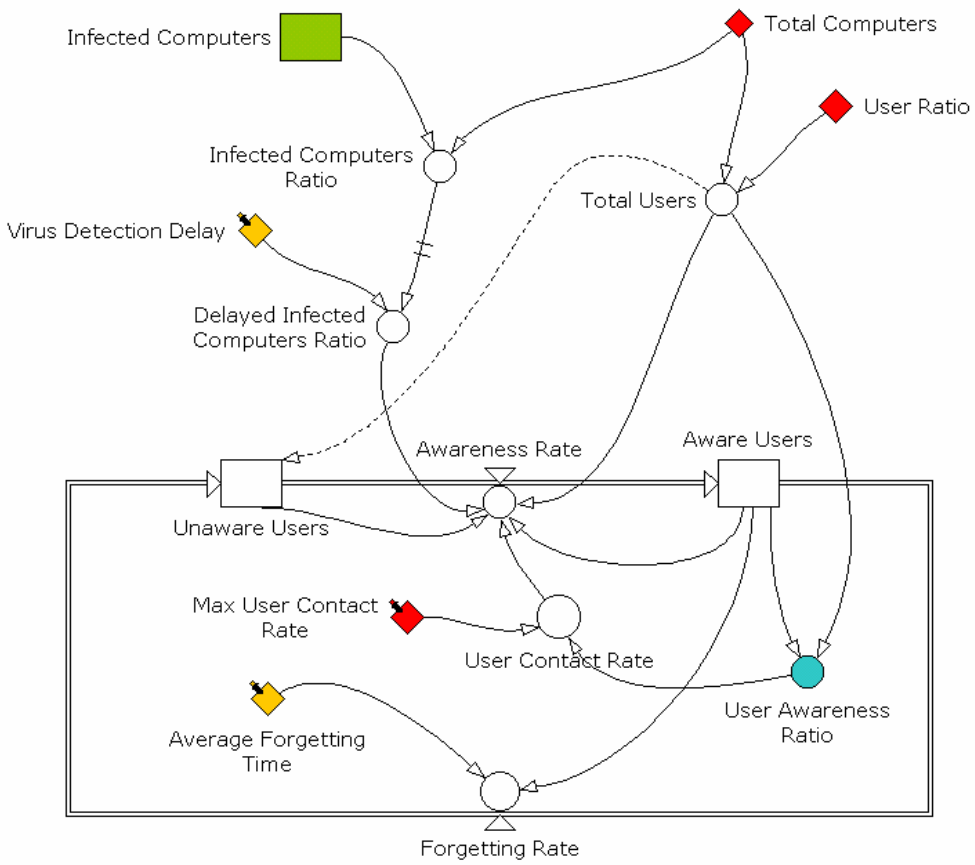
'Susceptible Computers'*('Preventive Immunization' + Diversification) / 'Immunization Delay'

- **Preventive Immunization:** The percentage of users that use anti-virus without being infected. Those people will never get infected by this virus.

- **Immunization:** The percentage of users that use an anti-virus. The anti-virus is applied with a certain delay. This delay takes into account the time it needs to create the anti-virus.

DELAYINF ('Countermeasure Efforts''Immunization Ratio' ,'Antivirus Creation Delay',3,0)*

Stock and Flow diagram for the User Awareness



The user awareness consists of 2 stocks which are: *Unaware* users ***(UU)***, *aware users* ***(AU)***. We have 2 flows which are: *awareness rate* ***(Ar)***, *forgetting rate* ***(Fr)***.

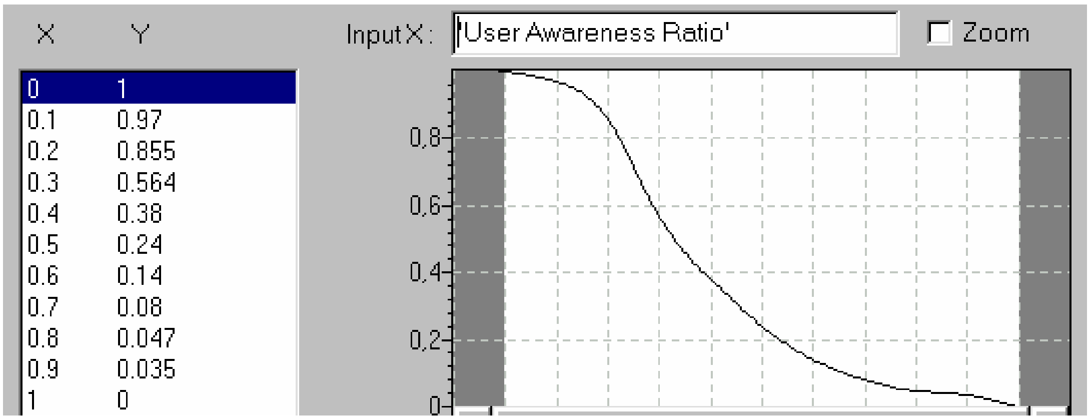
- **Forgetting rate (Fr):** After some time of being aware users will tend to forget or they do not pay any more attention to the threat. This is why we have included this forgetting rate.

  'Aware Users'/'Average Forgetting Time'

- **Awareness rate (Ar):** Unaware users will become more and more aware of the threat as the number of infected computers is growing. We make the hypothesis that we do not see the real infected computer ratio but there is a delay between the time we perceive the threat and its actual state, in our model this is the delayed *infected computer ratio* ***(dICR)***. The more infected computer the higher will be the awareness rate.

IF ('Unaware Users'>0) 'Unaware Users''Delayed Infected Computers Ratio'*'User Contact Rate'*'Aware Users'/'Total Users' ELSE 0*

- **User contact rate:** The user contact rate measures how many people are contacted per person per time period. The higher this value the faster people will be aware of the threat. We do not consider this contact rate as a constant because in the beginning of the threat people will tend to communicate a lot about it but as time passes, the contact rate will decrease. For example, there is almost no mail informing people about viruses that are more than 6 months. So we have chosen to give the *user contact rate* this shape below. We have used the ration of *aware user* because we consider that when people will stop alerting other if they have done it a couple of time unless there is a new virus.



X	Y
0	1
0.1	0.97
0.2	0.855
0.3	0.564
0.4	0.38
0.5	0.24
0.6	0.14
0.7	0.08
0.8	0.047
0.9	0.035
1	0

- **User Awareness Ratio:** The ratio of users, aware of the threat over total number of users.

'Aware Users'/'Total Users'

- **User Ratio:** Number of users per computer. It is possible to have more users than computers if we consider the user ratio as the average number of users using one computer.

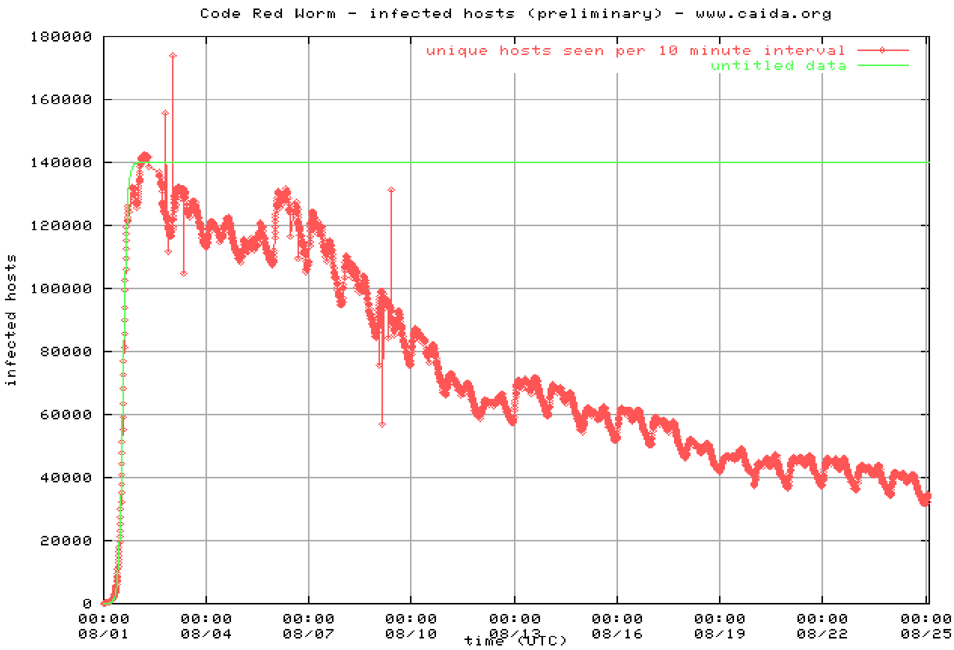
- **Virus detection delay:** Time it takes to discover that there is a virus. The bigger this delay, the longer time it will take a user (on average) to perceive the threat.

- **Delay Infected Computer Ratio:** The delayed ratio of infected computers. After some time the users will perceive that there is an infection.

DELAYINF('Infected Computers Ratio', 'Virus Detection Delay',2,0)

We use a second order time delay function.

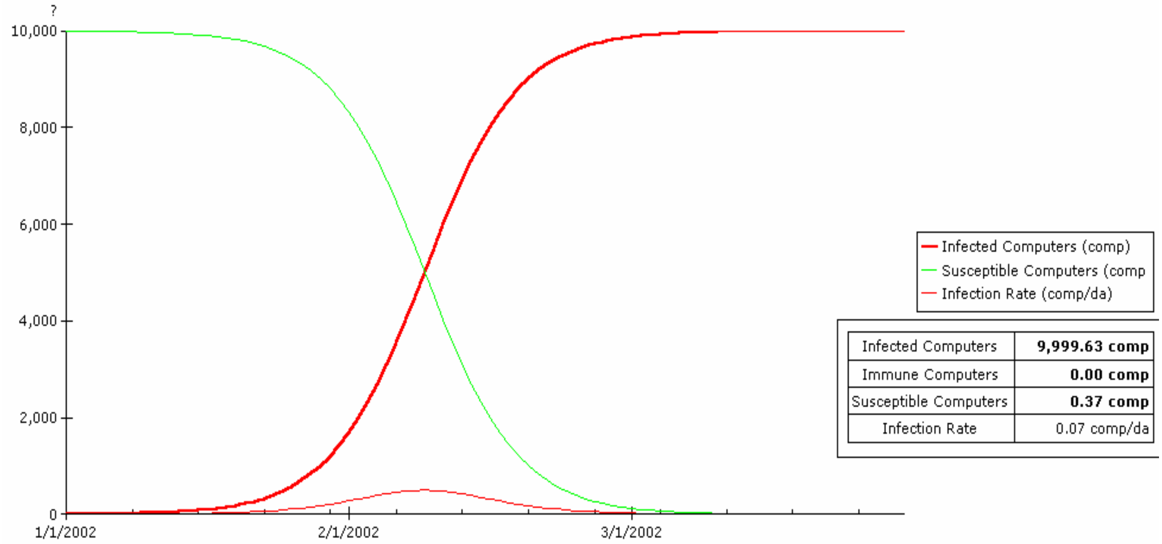
<u>Code Red Worm Infection</u>



This graph shows the propagation of the Code Red worms over a period of 25 days. We notice that there is a strong increase in the number of infected computers, as people starts to be aware of the virus, the infection rate decreases. This graph is taken from CAIDA (www.caida.org).

This is the kind of behavior that we expect from our model also.

<u>Results</u>



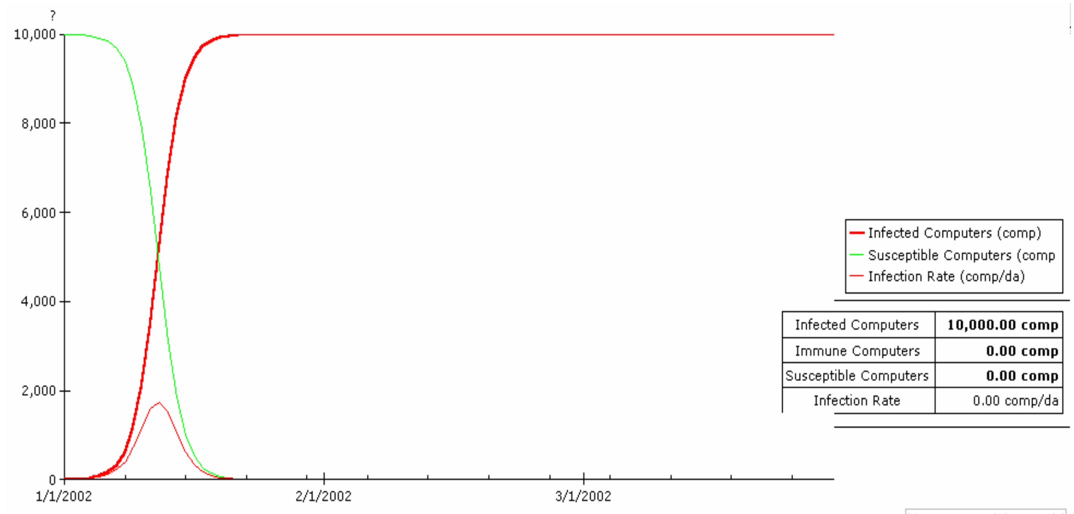
Total Computers	**10,000.00 comp**
Initially Infected	**5.00 comp**
Comp Contact rate	0.20 comp/comp/da
Virus type	0.00

Cleaning Ratio	0.00
Diversification Ratio	0.00
Preventive Immunization Ratio	0.00
Immunization Ratio	0.00

Immunization Delay	1.00 da
Cleaning Delay	1.00 da
Virus Detection Delay	1.00 da
Antivirus Creation Delay	1.00 da

User Ratio	1.00 user/comp
Max User Contact Rate	10.00 user/user/da
Average Forgetting Time	120.00 da

In this graph we see the effect of having an immunization rate and a preventive immunization rate that is always zero. After some time all the computers get infected. The infection rate will rise until the number of susceptible computer goes below the number of infected computer. We have the time period on the x-axis and the number of computer on the y-axis.



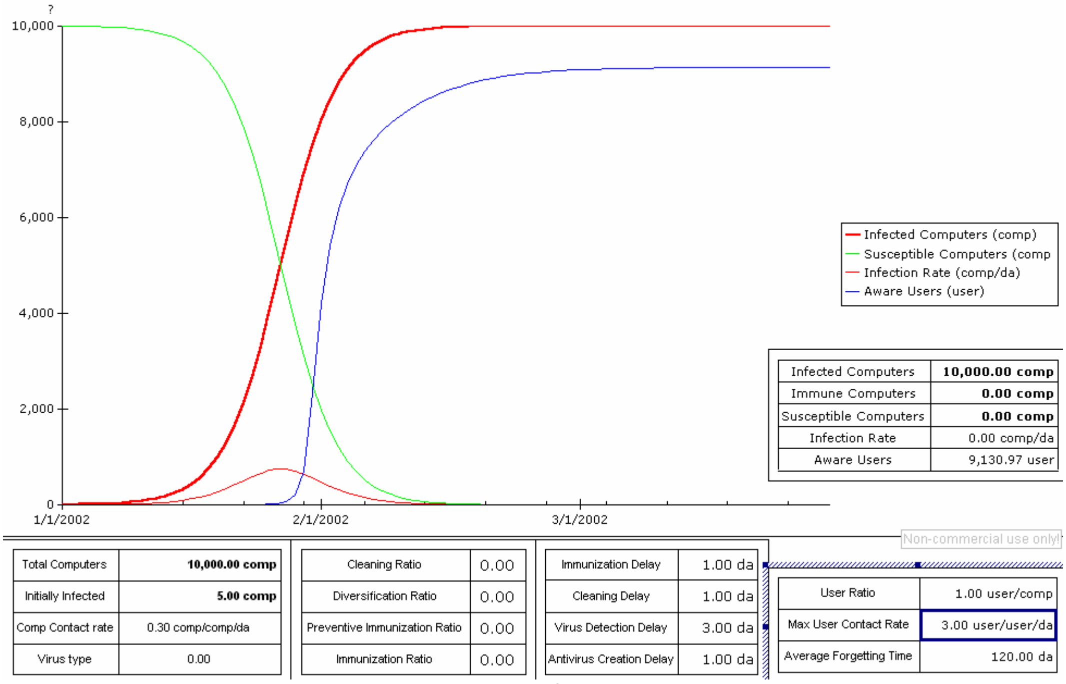
Total Computers	**10,000.00 comp**
Initially Infected	**5.00 comp**
Comp Contact rate	0.70 comp/comp/da
Virus type	0.00

Cleaning Ratio	0.00
Diversification Ratio	0.00
Preventive Immunization Ratio	0.00
Immunization Ratio	0.00

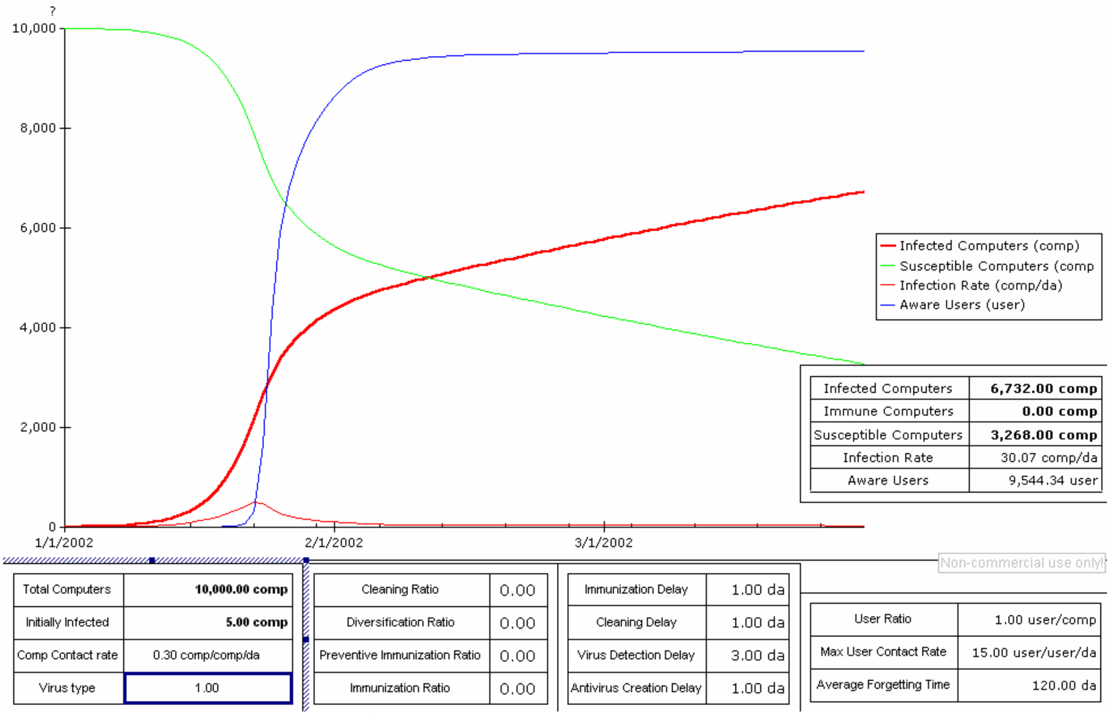
Immunization Delay	1.00 da
Cleaning Delay	1.00 da
Virus Detection Delay	3.00 da
Antivirus Creation Delay	1.00 da

User Ratio	1.00 user/comp
Max User Contact Rate	10.00 user/user/da
Average Forgetting Time	90.00 da

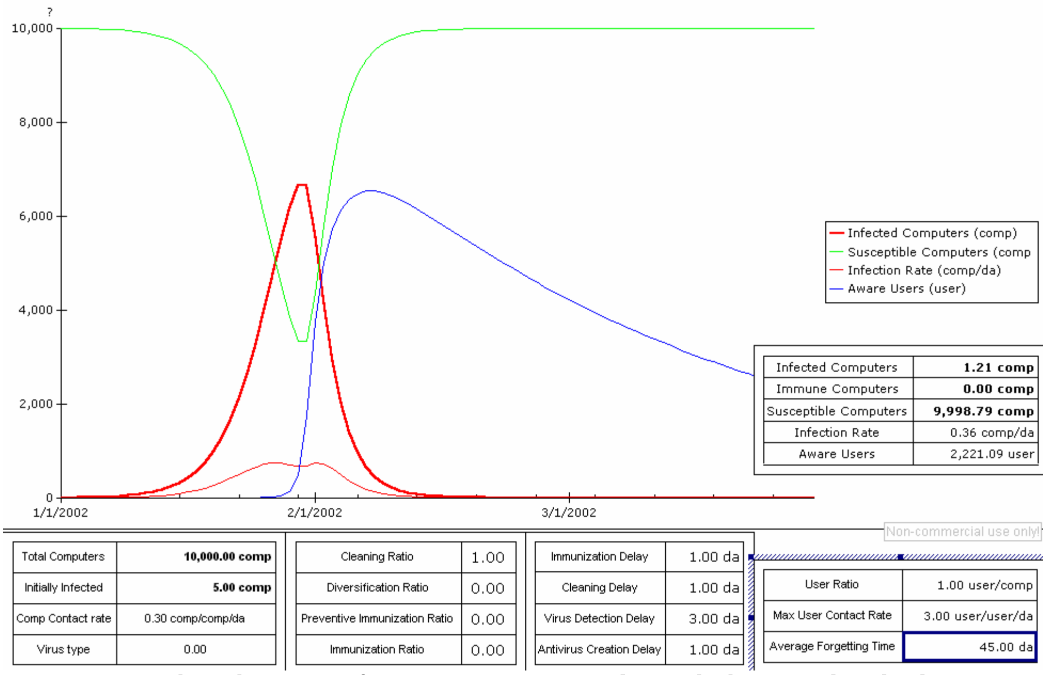
By increasing the contact rate, the infection propagates faster. High contact rate will be the characteristic of viruses that used mass mail to propagate.



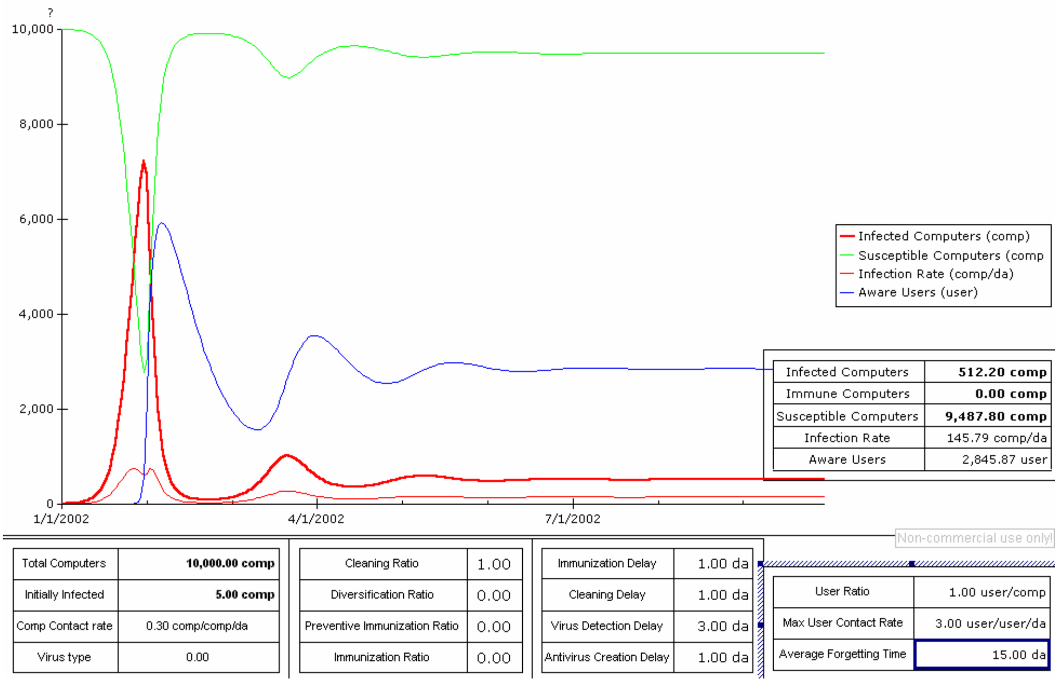
The blue curve represents the user awareness. It is influenced by the *Max User Contact Rate, the Average Forgetting Time & the Virus detection Delay.*



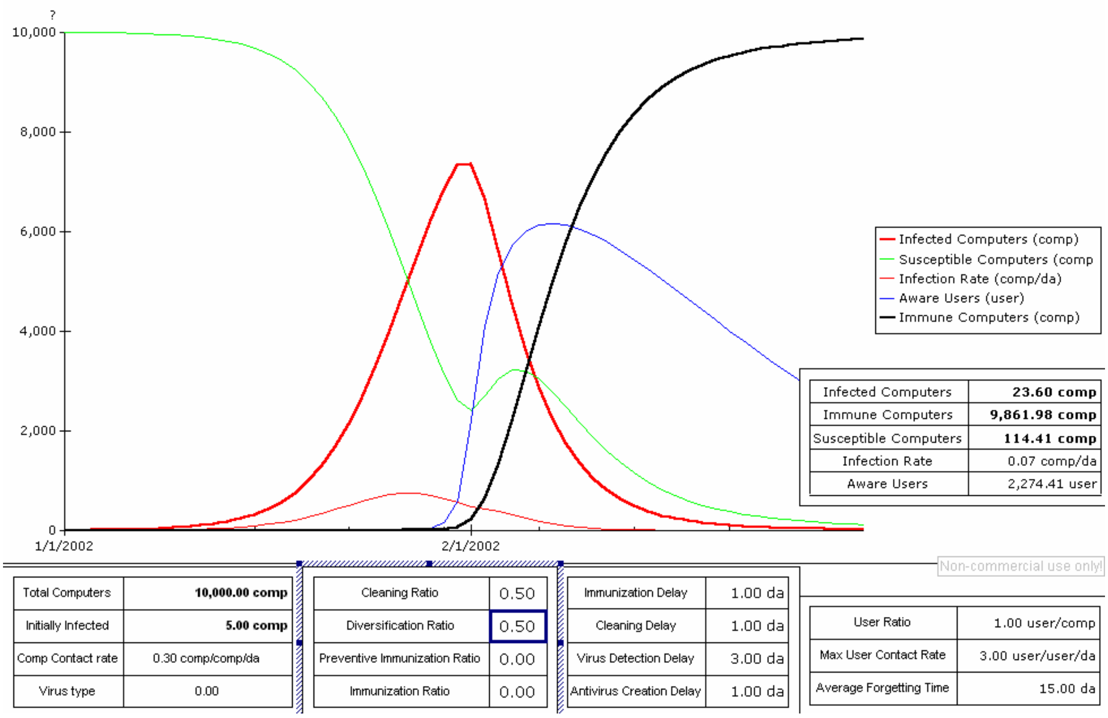
User Awareness can prevent the infection rate to get too high. This example was run without *immunization*. So if people are aware and stay aware they can prevent some type of viruses to propagate too fast. This can give time to create a “vaccine”.



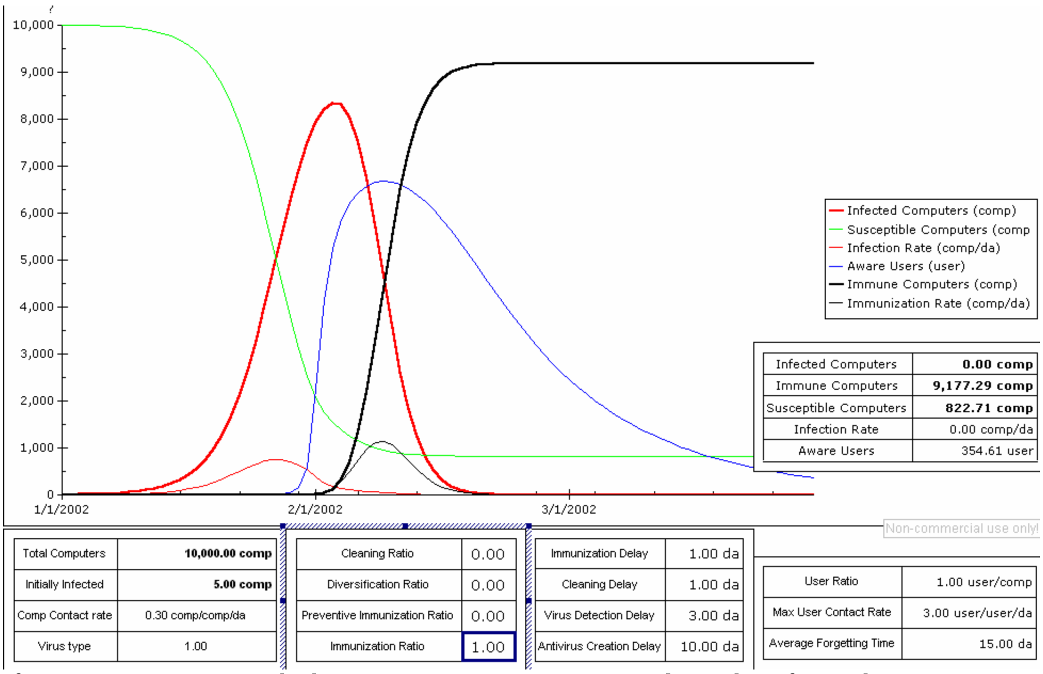
In some cases, where the average forgetting time is not too low and where people only clean their computers, it is possible to eradicate the infection. But the cleaning delay must be quite small, here it is 1 day. That means users should clean their computer every day. However if the contact rate is higher, it might not be possible to get the number infection computers to zero.



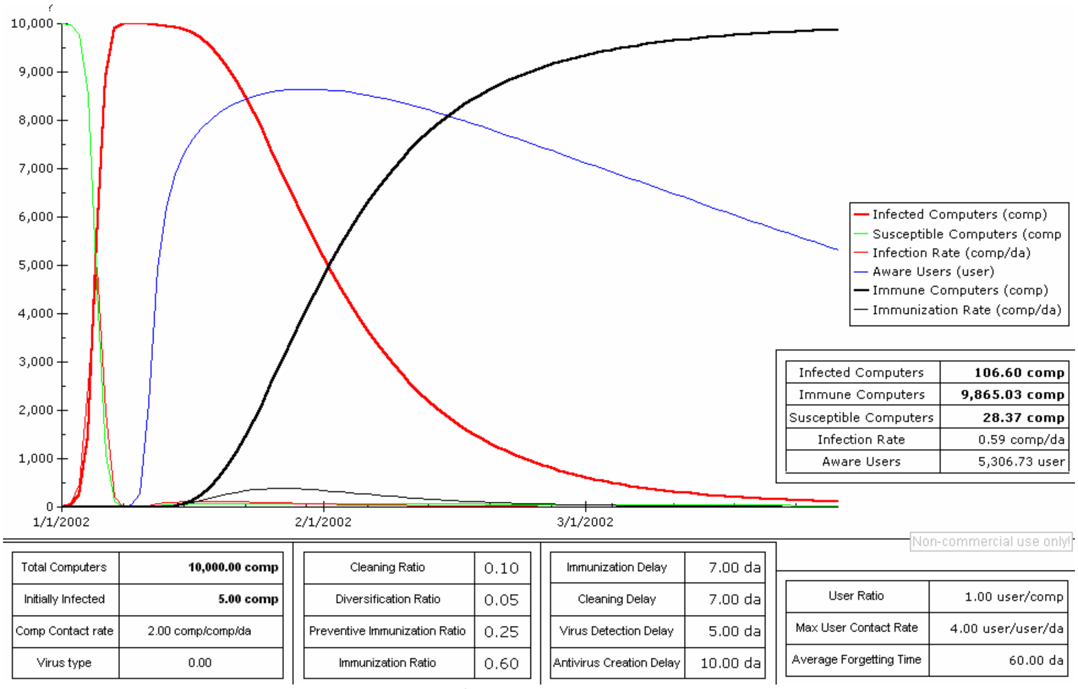
Using only cleaning may induce oscillations in the number of infected computers. This is due to the fact that by cleaning the number of infected computer is not reduced completely to zero, but to a very small number, which over time will create a new infection. The amplitude of the oscillation will decrease over time, because people are already aware of the virus, so that they can act in time to clean.



Diversification combine with *Cleaning* can eradicate the threat also. We remind that an immune computer cannot be infected again by the same virus.



If we use immunization, which means an anti-virus, we can eradicate the infection but we need to implement the immunization in good time otherwise the virus may have time to propagate and infect many computers.



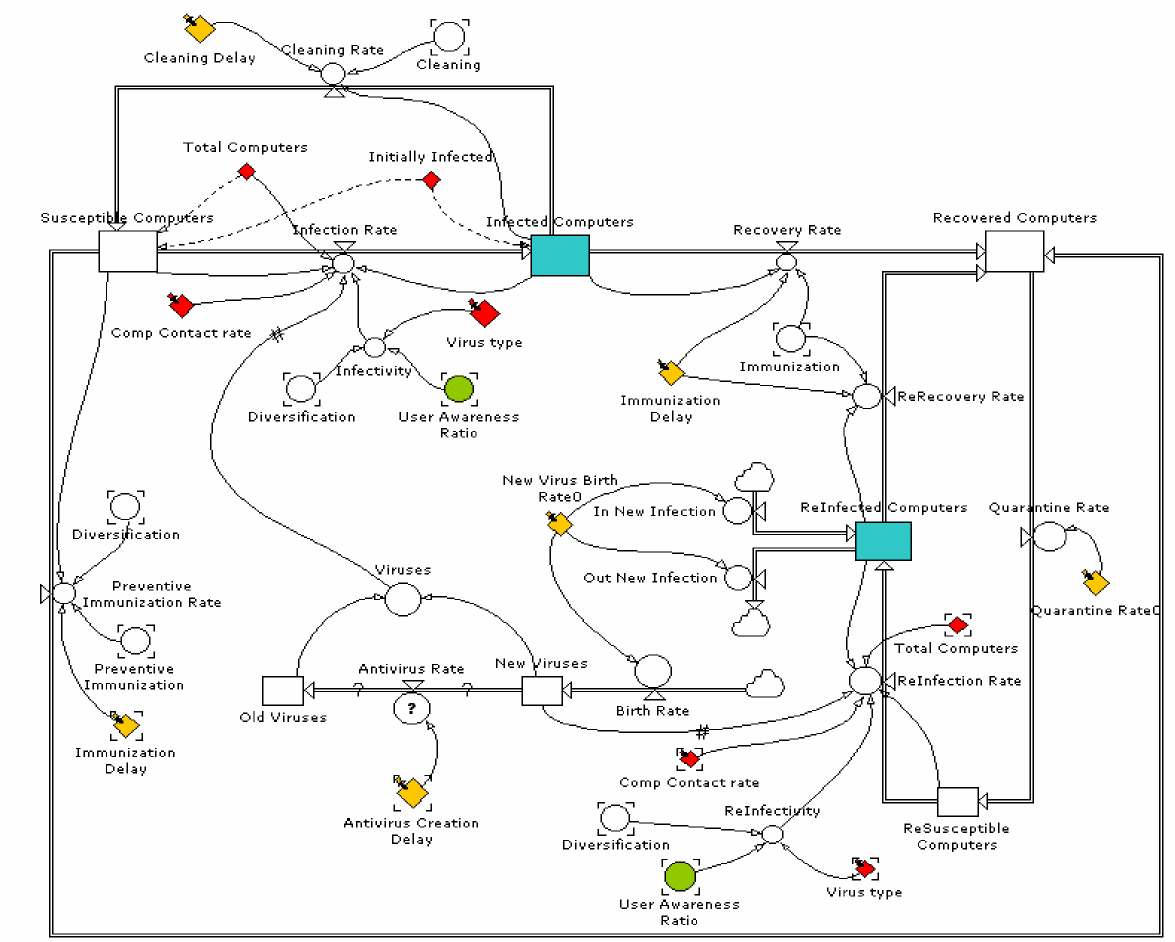
With this simulation result we have tried to fit the "Code Red worm" shows previously. For this behavior to occur we need a high contact rate and at the same time we need users to immune their machine with an anti-virus program in order to decrease the number of infected computers. If we decrease the contact rate by using diversification, we may prevent this kind of abrupt increase in the number of infected computers.

2. Case study for N virus (with N greater than 1)

In the case of N viruses, things become more complicated to model.

<u>Working hypothesizes</u>

- When a computer is infected, it stays immune for a period of time which depends on the average arrival of time of new viruses. After this time computers that were immune will become susceptible to be infected. The main problem results in the fact that an infected computer cannot be infected again by the same virus but at the same time it is possible to find computer that are infected by an old virus and other that are infected by a new virus. So we see the need to have at least two separate flows if we want to allow two kind of virus to be present during a period of time.
- We suppose that old viruses disappear after a certain period of time. Which means that they won't be able to create an epidemic again.



In this diagram we have tried to extend the system for N viruses but problems arise when we want to use PowerSim. First to introduce a new virus in the system we need to take into consideration the fact that old infected computer exist. Those old infected computers cannot propagate on new computers because those new computers have an anti-virus program. But at the same time we cannot remove those old computers because the old viruses can still propagate at the same time as the new one.

Discussion

Those graphs reveal two main points. User awareness is a key factor for virus propagation. The more people are aware the lower will be the infection rate. For example, if people pay attention before opening attachment, some viruses may not propagate so fast.

We have also seen that diversification can be an important factor to prevent infection because viruses will be confined in a smaller group of machine which means that the infection rate will be lower.,