Modelling Infectious Diseases in Virtual Realities

The „Corrupted Blood“ plague of World of Warcraft ™ from an epidemiological perspective

24C3
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Me, myself and I

- 1982 Commodore 64
- 1996 MSc Biology
- 2000 MSc Epidemiology
- 2004 ♬ ♬ ♬ Irene ♬ ♬ ♬
- 2004+ State and Federal Public Health Institutes
World of Warcraft

• Massively multiplayer online role playing game (MMORPG) by Blizzard Entertainment
• Players create „Avatars“ from a set of races and classes, can learn professions
• Interaction with other Avatars
• LOTS of out-of-game activity
World of Adventure

• Avatars adventure the virtual world „Azeroth“ and progress from Level 1 to Level 60 (70, 80)
• Each new level makes Avatars more powerful: more life, talents, spells, better armoury etc.
• Powerful enemies („Bosses“) can only be defeated by several coordinated max. level Avatars („raid“)
09/13 2005, Azeroth: Zul‘Gurub

• Release of new gaming content: Blood God „Hakkar the Soulflayer“ for high level Avatars
• During battle, Hakkar cast the spell „corrupted blood“ (CB) on random Avatars
• CB hit with severe damage once plus additional damage over time; duration 10 seconds
• CB spread from Avatar to Avatar: INFECTIOUS
• CB was never meant to leave Zul‘Gurub, but:
  – Infected Avatars could teleport to cities
  – Hunters could dismiss their infected pets in Zul‘Gurub and later call them back –still infected- in cities
However, no attempt at modelling it, yet…
Mathematical Modelling of Populations

• 1798 Malthus: population grows exponentially, but food supply linearly, therefore catastrophe
• 1925/26 Lotka Volterra: Predator–Prey cycles
• 1927 Kermack-McKendrick „SIR“ disease model
• 1977 Baroyan, Rvachev, Ivannikov (Moskau): modelling of influenza epidemics in the USSR
• Post 9/11: massive interest in disease modelling
  – Bioterrorism (smallpox)
  – Pandemics (influenza, H5N1, SARS)
• Models have substantial policy impact (stockpiling, treatment priorities, cost-benefit)
Models: Different Flavours

• Compartimental Models (classic SIR models)
  – Deterministic
  – Stochastic
• Individual/ agent based systems (US: stochastic)
• Branching Models
• Complex models require more assumptions and parameter estimations
• “Describing complex, poorly-understood reality with a complex, poorly understood model is not progress“ J. Maynard Smith (credit: Peter White)
Keep it SIRmple

- Susceptible (S): are healthy, but can be infected
- Infectious (I): are sick and infectious
- Recovered (R): recovered from disease and are immune to it
- Assumption: homogeneous mixing
- Challenge: estimate rates (arrows) from data
Transmission Rate Formula P. White

- Rate of contacting others (people/time): $c$
- Rate of contacting infectious: $c \times \frac{I}{N} \ (N=S+I+R)$ (I/N is proportion of infected in population)
- Rate of transmission from infecteds: $p \times c \times \frac{I}{N}$ („force of infection“, $p$ is transmission probability)
- Total transmission rate in population: $S \times p \times c \times \frac{I}{N}$
- $S$, $I$ change with time, product $SxI$ is non-linear
Simulation: Berkely Madonna

```plaintext
METHOD RK4
STARTTIME = 0
STOPTIME = 120
DT = 0.02
; one timestep is one second

d/dt(Susceptible) = delta*Graveyard - beta *Susceptible*Infected/N

d/dt(Infected) = beta*Susceptible*Infected/N - sigma*Infected

d/dt(Graveyard) = sigma*Infected - delta*Graveyard

N = Susceptible + Infected + Graveyard
prevalence = Infected/N*100

init Susceptible = NO - IO - Rnull
init Infected = IO
init Graveyard = Rnull

NO = 3000 ; 3000 player on server
IO = 1 ; one infected
Rnull = 0

delta = 1/(5*60) ; mean duration of immunity=5 minutes spent on graveyard before coming back
sigma = 1/4 ; recovery rate Infected > graveyard, WoW_death after 4 seconds
beta = p*c ; force of transmission
p = 1 ; transmission probability, here everyone gets infected
```

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24C3 Modelling Infectious Diseases in Virtual Realities by Florian Burckhardt
## Disease Parameters

<table>
<thead>
<tr>
<th></th>
<th>Measles</th>
<th>Syphilis</th>
<th>Norovirus „projectile vomiting“</th>
<th>Corrupted Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Incubation period</strong></td>
<td>10 days</td>
<td>1-3 weeks</td>
<td>10 hours</td>
<td>0 sec</td>
</tr>
<tr>
<td><strong>Duration of infectiousness</strong></td>
<td>8 days</td>
<td>(1 year)</td>
<td>2-4 days</td>
<td>10 sec</td>
</tr>
<tr>
<td><strong>Transmission probability $p$</strong></td>
<td>95%</td>
<td>30%</td>
<td>high</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Immunity</strong></td>
<td>yes, lifelong</td>
<td>weak</td>
<td>only against subtype</td>
<td>no</td>
</tr>
<tr>
<td><strong>Mode of transmission</strong></td>
<td>Droplet (airborne)</td>
<td>Sexually !condoms protect!</td>
<td>fecal-oral, droplet, fomite</td>
<td>magic (droplet like)</td>
</tr>
</tbody>
</table>
Low/Mid Level Avatar: SIRS

- **Susceptibles** → **Infectious** → **Graveyard „immune“**

  - **S** Transmission → **I**
  - **I** WoW death „Recovery“ from Disease → **R**

  Resurrection = loss of immunity

- **WoW**: death is not permanent
- Graveyard compartment: confers CB immunity
- After resurrection, Avatars are susceptible again
- SIRS Model (or rather SIGS Model)
SIRS Model (low/mid Lv Avatar)

3000 Players
1 Infected at start
2 contacts per second
85% on graveyard
>>> Infection persists

1 Infected at start
1 contact every 2 seconds
50% on Graveyard
>>> Infection persists

500 Infected at start
1 contact every 5 seconds
after 6mins 0% on Graveyard
>>> Infection dies out
High Level Avatar: SIS

- Level 50+ Avatars are strong enough to survive „natural“ course of infection without dying first
- However, no immunity; can become reinfected
- SIS model, „classic“ sexually transmitted diseases model: syphilis, gonorrhea, chlamydia
SIS Model (high Lv Avatar)

**A**

1 Infected at start
1 contact every 2 seconds
80% Infected
>>> Infection persists

**B**

1 Infected at start
2 contacts per second
95% stay infected
>>> Infection persist

**C**

500 Infected at start
1 contact every 20 seconds
after 2 min 0% infected
>>> Infection dies out
Basic Reproductive Number $R_0$

• $R_0$ („$R$ naught“):
  – average number of secondary infections from one single infected in a totally susceptible population
  – „how many people does one infectious person infect if everybody is susceptible?“

• $R_0 = D \times c \times p$
  – $D$: mean duration of infectiousness
  – $c$: contact rate
  – $p$: transmission probability

• $R_0 \ (\text{CB SIS}) = 10 \times c \times 1$ (length of spell, 10s)
• $R_0 \ (\text{CB SIRS}) = 4 \times c \times 1$ (die after 4s)
What if...

- $R_0$: “how many people does one infectious person infect (if everybody is susceptible) ?“
- IF $R_0 < 1$ THEN epidemic fades out
  - $R_0$ (CB SIRS) = $4 \times c \times 1 < 1$
  - $c < 1/4$

Susceptible
Infected
Graveyard

500 Infected at start
1 contact every 5 seconds, c=1/5
after 6mins 0% on Graveyard
>>> Infection dies out
InteR₀ventions

- \( R_0 = D \times c \times p \)
  - \( D \): mean duration of infectiousness
  - \( c \): contact rate
  - \( p \): transmission probability
- Quarantine: reduce \( c \)
- Treatment: reduce \( D, p \)
- Airborne infections: face masks can reduce \( p \)
- Relax at home: reduce \( c \), maybe \( D \)
- WoW:
  - social distancing, stay out of cities (or on Orgrimmars rooftops)
  - „Healing“ made things worse by increasing \( D, (R_0) \)
  - Reload w0rld (VR only...?)
### R₀ of some diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>R₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measles</td>
<td>15-20</td>
</tr>
<tr>
<td>Foot and Mouth Disease (FMD), UK Feb 2001</td>
<td>Initially 8.4; animal movement restrictions: reduced to 1.3</td>
</tr>
<tr>
<td>Influenza</td>
<td>&lt;3</td>
</tr>
<tr>
<td>Smallpox</td>
<td>3-4</td>
</tr>
<tr>
<td>HIV</td>
<td>2-12 (&lt;! condoms: R₀&lt;&lt;1 !&gt;)</td>
</tr>
<tr>
<td>Corrupted Blood (SIS)</td>
<td>(D \times c \times p = 10 \text{sec} \times c \times 1) [50 \text{ (city: 5 contacts per second)}] [1 \text{ (countryside: one every 20s)}]</td>
</tr>
</tbody>
</table>
## Is WoW an Epidemic Simulator?

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Largest human-agent based system</td>
<td>Does not model human risk behaviour, no permanent death</td>
</tr>
<tr>
<td>Huge complexity, lots of fine tuning possible</td>
<td>Not representative: players do not reflect general population</td>
</tr>
<tr>
<td>Intense social interaction</td>
<td>Lack of external validity</td>
</tr>
<tr>
<td>Human decision and behavioural choices vs. computer simulations</td>
<td>No disease surveillance implemented</td>
</tr>
<tr>
<td>Multiple servers allow parallel observations</td>
<td>Ethical approval to allow Avatar to take part in a medical trial?</td>
</tr>
<tr>
<td>Geographical distribution of gameservers allows study of culture-dependent behaviour</td>
<td></td>
</tr>
</tbody>
</table>
Ideas for better virtual Epidemics I: Transmission Matrix

<table>
<thead>
<tr>
<th>infects</th>
<th>Human</th>
<th>Orc</th>
<th>Undead</th>
<th>Tauren</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>+++</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Orc</td>
<td>+</td>
<td>+++</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Undead</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Tauren</td>
<td>++</td>
<td>++</td>
<td>-</td>
<td>+++</td>
</tr>
</tbody>
</table>

• Account for interspecies transmission
• Undead spread disease anyway…
Ideas for better virtual Epidemics II

- Reintroduce infectiousness in WoW
- Add immunity, waning immunity (biowarfare!)
- Add vaccination
- Add incubation period
- Race specific diseases
  - Tauren: FMD, mad cow disease
  - Orcs: orchitis
  - Humans: measles
  - Elves: otitis externa (moldy ears)
- Collect & share data!
Links & References

• Short course on epidemiology of infectious diseases
  http://www.imperial.ac.uk/cpd/epidemiology/
• The untapped potential of virtual game worlds to shed light on real world epidemics, Lofgren ET, Fefferman NH, *Lancet Infect Dis* 2007; 7:625-29
• http://www.berkeleymadonna.com/
• Bapf
• http://www.burckhardt.de/docs.html
• All images taken for educational purposes only, © Blizzard Entertainment
Onyxia says: Game On!!

Thanx to
Bapf
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